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SOIL SCIENCE

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THE EFFECT OF GYPSUM ON SOIL REACTION

L. W. ERDMAN[1]

Iowa Agricultural Experiment Station

Received for publication April 12, 1921

INTRODUCTION

Gypsum has been used as a fertilizer for many years, and has often proven to be valuable especially when applied to small grains and clovers. The early investigators claimed that gypsum increased crop yields for a time, but its continued use failed to maintain those increases, and as it contained no nitrogen, phosphorus, or potassium, it was regarded as a soil stimulant. Several more recent investigations have indicated that the value of gypsum is probably due to its sulfur content, and to the indirect action it may have on other soil constituents. Recently many soils have been found to be deficient in sulfur, one of the essential plant-food elements, and sulfur requirements of certain crops are apparently much greater than formerly supposed. Since gypsum supplies this necessary element in an available form it may play an important rôle in soil fertility in those regions where sulfur is needed.

It is generally conceded that gypsum, $CaSO_4 . 2H_2O$, cannot replace lime as a means of correcting soil acidity, but there seems to be some difference of opinion as to whether or not when applied to soils it tends to made them acid. Gypsum is a neutral salt and its dissociation in pure water produces hydrogen and hydroxyl ions of equal concentration. It is quite natural to expect it to act in a similar way when dissolved in the soil solution. However, through crop production or bacterial activities there may be a utilization of either the sulfate or the calcium ion, leaving one or the other free to react with the soil constituents in such a way as either to increase or decrease the acidity of the soil. There is also the possibility of a chemical reaction, the calcium combining with the insoluble soil acids, leaving the readily soluble sulfate ion which theoretically may cause a certain amount of acidity. The object of this work was to determine as far as possible by laboratory experiments the effect of gypsum on soil reaction.

HISTORICAL

In reviewing the literature on the effect of gypsum on soil reaction, the investigations reported may well be considered from two viewpoints: first,

[1] The writer wishes to make acknowledgments to Dr. P. E. Brown and Prof. H. W. Johnson for helpful suggestions and criticisms offered during the progress of this work.

experiments dealing with gypsum itself; and, second, experiments showing the effect of acid phosphate on acidity. Acid phosphate contains about 60 per cent gypsum and consequently any effect of this fertilizer on acidity may indirectly be interpreted as due at least partly to the presence of gypsum.

In 1910 Gardner and Brown (9), using the Veitch method, tested the lime requirement of the general fertilizer plots of the Pennsylvania station. Plots 13 and 33 received gypsum at the rate of 320 pounds per acre every two years. After 30 years the average of all the check plots had a lime requirement of 172 pounds of CaO per acre, as compared with 146 pounds for the gypsum plots Frear (8) concluded from these results that where land plaster was used the land was no more acid than where no fertilizer at all was applied.

Ames and Schollenberger (1) used the Hopkins potassium nitrate and the vacuum method and found that gypsum applied with manure decreased the acidity of the soil.

Lipman (19) stated that gypsum possesses no alkalinity and therefore will not be of any assistance nor act as a corrective to a sourness or acidity in soils.

Skinner and Beattie (26) used a number of square-rod plots to test the effects of fertilizers and soil amendments on soil acidity. $CaSO_4$ was used at the rate of 500 pounds per acre each year and after 5 years the plots were tested for lime requirement by the Veitch method. They concluded that the soil in each plot to which $CaSO_4$ had been added was more acid than the untreated plot growing the same crop. The average lime requirement for the $CaSO_4$ plots in excess of the check plots was 343 pounds of $CaCO_3$ per acre.

Singh (25), using pot cultures, tested the soil (after cropping) by the modified Tacke method and found that the acidity was increased by the application of gypsum, the larger amount giving the greatest increase.

Connor (7) tested gypsum as a means of correcting soil acidity on two types of very acid soils. The rate of application was 2 tons of gypsum per million pounds of soil. The gypsum treatment showed an actual decrease in acidity when compared with the check pots, the average decrease for the two soils being 580 pounds of $CaCO_3$ per million pounds of soil by the Hopkins potassium nitrate method, and 937 pounds by the Jones calcium acetate method.

Veitch (29) tested the lime requirement of the soil from a number of the plots in the 5-year rotation experiments at Wooster, Ohio, and found that acid phosphate had slightly reduced the acidity of the soil.

Brooks (4) concluded from his work that the use of an acid phosphate (dissolved bone black), at least had not increased the necessity for lime and, on the contrary, it seemed that the bone black had reduced the acidity.

Conner (6), testing the experimental plots at Purdue, observed that soils treated with acid phosphate for 20 years showed less acidity than soils that had received no treatment.

Ames and Schollenberger (1) claim that acid phosphate did not have any important influence on the depletion of the soil's supply of bases.

Bear and Salter (2) tested the residual effects of fertilizers and concluded that the use of manure or fertilizers (with the exceptionof K_2SO_4) had a tendency to decrease the acidity of the soil.

More recently Plummer (22) studied soil reaction by means of the hydrogen electrode. The plots to which acid phosphate had been added did not show any greater hydrogen ion concentration than the ones used as controls. These plots had received rather heavy annual applications of this fertilizer for the past 15 years, the total amount being over 3,000 pounds per acre.

Some of the above-mentioned investigations show a difference of opinion regarding the effects of gypsum on soil acidity. However, in every case where it is claimed that gypsum produced acidity the results obtained by the particular lime-requirement method employed are so small as to be well within the limit of experimental error, since it is doubtful whether any lime-requirement method in use at the present time is accurate to 400 pounds of calcium carbonate per acre. All the work reported relating to the effect of acid phosphate on acidity shows conclusively that this fertilizer tends to decrease rather than increase soil acidity.

EXPERIMENTAL

Two laboratory experiments were planned to determine:

(a) The effect of gypsum on an acid soil, a neutral soil, and a basic soil;

(b) The effect of gypsum on a soil with different degrees of acidity.

Experiment I

The three soils used in the first experiment were obtained from different locations in the Wisconsin drift soil area and all would be classed as Carrington loam.

The acid soil had a lime requirement of 2260 pounds of $CaCO_3$ per acre as determined by the modified Tacke method (27).

The neutral soil gave a negative test for acidity by the modified Tacke method and the Truog qualitative test.

The basic soil was obtained from a typical Iowa alkali spot and was very high in calcium bicarbonate.

The soils were air-dried and 2500 gm. of each soil was placed in 6 1-gallon pots. Treatments were made as follows:

Pot 1. Check
Pot 2. 100 pounds gypsum per acre
Pot 3. 200 pounds gypsum per acre
Pot 4. 500 pounds gypsum per acre
Pot 5. 1000 pounds gypsum per acre
Pot 6. 2000 pounds gypsum per acre

The gypsum was mixed with the entire contents of the pots and distilled water added to bring all the soils to their optimum moisture content. The pots were then weighed and covered loosely with a wooden block to prevent

rapid evaporation. The pots were kept in the laboratory at ordinary room temperature. A record was kept of the amounts of soil removed by sampling and every 2 weeks during the experiment the pots were reweighed and the moisture content maintained by additions of distilled water to weight. This experiment was begun March 3, 1920, and discontinued January 10, 1921.

The soil used in the second experiment was the same neutral soil as used in experiment I.

A preliminary test was made to compare the effect of gypsum on the hydrogen-ion concentration of a soil, made acid by treatment with H_2SO_4 and HCl. For this test 1000 gm. of neutral soil was used with each treatment and the hydrogen-ion concentration of a suspension from each treated soil determined. Another test was made to compare the effect of gypsum on the hydrogen-ion concentration of pure water made acid by treatments with H_2SO_4 and HCl, and for this test 200 cc. of double distilled water was used with each treatment. The acid treatments were calculated to give the same hydrogen-ion concentration. The tests may be best understood by the treatments as shown in table 1 which also gives the results.

TABLE 1

Hydrogen-ion concentration of a soil suspension and of pure water made acid by treatments with sulfuric and hydrochloric acids

NUMBER	TREATMENT	SOIL SUSPENSION	WATER
		pH	*pH*
1	Check	7.13	7.60
2	H_2SO_4, 1 gm.	6.39	1.28
3	HCl, 1.93 gm.	6.39	1.18
4	H_2SO_4, 1 gm.; 2 gm. gypsum	6.28	1.21
5	HCl, 1.93 gm.; 2 gm. gypsum	6.25	1.15
6	H_2SO_4, 1 gm.; 4 gm. gypsum	6.23	1.18
7	HCl, 1.93 gm.; 4 gm. gypsum	6.35	1.15

It will be noticed from table 1 that upon the addition of 2 gm. of gypsum to the soil treated with H_2SO_4 and HCl, the hydrogen-ion concentration remained the same for each acid. With the 4-gm. gypsum treatment there was an increase in acidity for the H_2SO_4 amounting to 0.12 pH over the HCl treatment. In the case of the water solution the pH values were practically the same for 2-gm. and 4-gm. gypsum treatments, and also each acid showed the same pH value. The results of these tests clearly showed that sulfuric and hydorchloric acid acted in the same manner as far as the reaction in the soil and water was determined by the hydrogen electrode.

Accordingly, for the second experiment hydrochloric acid was used to make the soil of varying degrees of acidity, in order to eliminate the sulfate ion which would be produced from the sulfuric acid.

For this experiment 16 1-gallon glazed pots were filled with 4200 gm. of the air-dried neutral soil and treatments made as follows:

Pots 1 and 2. Check
Pots 3 and 4. 500 pounds gypsum per acre
Pots 5 and 6. 4000 pounds $CaCO_3$ per acre
Pots 7 and 8. 4000 pounds $CaCO_3$ per acre plus 500 pounds gypsum
Pots 9 and 10. HCl equivalent to 2-ton lime requirement
Pots 11 and 12. HCl equivalent to 2-ton lime requirement plus 500 pounds gypsum
Pots 13 and 14. HCl equivalent to 4-ton lime requirement
Pots 15 and 16. HCl equivalent to 4-ton lime requirement plus 500 pounds gypsum

The gypsum and $CaCO_3$ were mixed with the 4200 gm. of soil, and the hydrochloric acid was added to the distilled water required to bring the soil to the optimum moisture content. The pots were weighed and covered in the same manner as those in experiment 1. This experiment was begun July 30, 1920, and discontinued December 29, 1920.

Methods

Lime requirement. The method used for determining the lime requirement in these experiments was a modification of the one designed by Tacke (28). The original method consisted of treating the soil with an excess of calcium carbonate and water, bubbling hydrogen through the mixture and collecting the carbon dioxide expelled with an alkaline absorbent contained in a Pettenkofer absorption tube. The lime requirement was calculated from the carbon dioxide thus obtained.

Several modifications of this method have been used by investigators in this country. Wheeler, Hartwell, and Sargent (30) boiled the mixed soil and $CaCO_3$ solution in water and determined the carbon dioxide evolved.

Ames and Schollenberger (1) used a method similar to the one just described, the essential difference being the temperature employed. The boiling was conducted *in vacuuo* and the temperature need not exceed 50° C. This step was taken to reduce the decomposition of the organic matter by heat to a minimum.

Knight (18) mixed a weighed quantity of soil with precipitated calcium carbonate, added about 25 cc. of a neutral salt solution, boiled for a definite period and determined the carbon dioxide evolved by the Parr method.

The modification used in this work was the one described and used by Stephenson (27). A machine was used which held 8 300-cc. Kjeldahl flasks and 8 sodium-hydroxide towers. Twenty grams of soil, 2 gm. of calcium carbonate and 50 cc. of CO_2-free water were placed in the flasks and the carbon dioxide evolved during the shaking was absorbed in a solution containing 50 cc. 0.2 *N* NaOH and 100 cc. of CO_2-free water. A stream of CO_2-free air was constantly drawn through the system and continuous shaking employed for 5 hours. Determinations were made in duplicate, and blanks, without the calcium carbonate solution, were run for each determination. Results were obtained by double titration with phenolphthalein and methyl orange. Thus using a 20 gm. sample of soil and titrating against 0.04*N* acid, each cubic centimeter of

the titration represents a lime requirement of 400 pounds of calcium carbonate per two million pounds of soil. In the results the blank is always subtracted.

Acidity. In these experiments the acidity, or hydrogen-ion concentration, of the soil was measured by the hydrogen electrode. The possibilities of this method of studying soil reactions have been realized only during comparatively recent years. Gillespie (10) used the electrometric and colorimetric methods and determined the hydrogen-ion concentrations of a number of soils of different types. Sharp and Hoagland (24) studied the hydrogen-ion concentration in various soil suspensions and in soil extracts, and noted the effect of certain factors on the hydrogen-ion concentration. Hoagland and Sharp (15) found that the hydrogen-ion concentration of soil suspensions of acid soils was not markedly affected by increasing the CO_2 content up to 10 per cent.

Gillespie and Hurst (12, 13) studied the hydrogen-ion concentration of two soil types, the Caribou loam and Washburn loam, and showed a correlation between hydrogen-ion concentration and the occurrence of the potato scab. Martin (21) studied the relation of the potato-scab organism to soil acidity as measured by the hydrogen-ion concentration, and also for determining the relation of hydrogen-ion concentration of extracts from soils to which varying amounts of sulfur had been added.

Plummer (22) used the hydrogen electrode method in comparing hydrogen-ion concentrations of a number of untreated soil samples and also of a few samples of soil treated with different fertilizers. Kappen and Zapfe (17) measured the hydrogen-ion concentration of peat soils and of peat and humus-forming plants.

Gillespie (11) proposed a colorimetric method for the determination of hydrogen-ion concentrations without buffer mixtures. His indicators were chosen from the series of Clark and Lubs (5). Wherry (31, 32) described a set of six indicators suitable for the study of soil reactions in the field, and gave detailed instructions for making the test.

Several investigators have compared the hydrogen-ion concentration of soil extracts with certain lime-requirement methods. Knight (18) found that the vacuum method approached nearer to the lime requirement as shown by the hydrogen electrode than any of the five methods studied. The Veitch method showed results considerable lower.

Blair and Prince (3) observed a close correlation between the hydrogen-ion concentration of the soil extract and the lime requirement by the Veitch method. Soils having a pH value of 6.7 or over were alkaline by the Veitch method. Joffe (16) found that soils having a pH value 6.6 to 6.8 before evaporation indicated that the end point of the lime requirement by the Veitch method had been reached.

The apparatus used in determining the hydrogen-ion concentration in this work was similar to that described by Sharp and Hoagland (24) which is a modification of Hildebrand's (14) apparatus. A normal calomel cell and an

accurate Weston voltmeter were used in the present work. Results could be obtained with this apparatus accurate to within 0.05 pH. Fifteen grams of soil and 30 cc. of double distilled water were used in the manipulation of the test, duplicate determinations being made for each sample. The voltmeter readings were transformed into pH values from the tables prepared for this purpose by Schmidt and Hoagland (23).

Residual Carbonates. Residual carbonates were determined by the method of MacIntire and Willis (20). The same apparatus was used as that described for determining the lime requirement. Twenty grams of air-dry soil, and 50 cc. of 1 to 15 phosphoric acid solution, prepared by diluting 85 per cent H_3PO_4 with CO_2-free water, were placed in the flasks. The flasks were constantly shaken for 30 minutes. A current of CO_2-free air was drawn through the system at a very slow rate for the first 10 minutes. The second 10 minutes the rate was slightly increased and during the last 10 minutes the air was drawn through fairly rapidly. The carbon dioxide evolved was absorbed in a sodium hydroxide solution, and results were obtained by double titration with phenolphthalein and methyl orange.

Discussion of results

Twenty-gram samples of the wet soils were taken from the pots of the first experiment at different times and tested for their lime requirement by the Tacke method as described. Correction was made for moisture in the samples and the results were figured in pounds of $CaCO_3$ per 2,000,000 pounds of soil. It may be well to call attention at this point to the accuracy of this method as it was used in this work. Duplicate determinations usually checked to within 200 pounds of $CaCO_3$ per acre, but occasionally differences were obtained as much as 400 pounds of $CaCO_3$. Consequently it would be safe to say the method is accurate only to 400 pounds of $CaCO_3$ per acre.

The results for the three soils, acid, neutral, and basic, are grouped under table 2. It will be seen from the data presented for the acid soil, that the first determinations made on March 18, showed wider variations between the check pot and the gypsum treatments than at any other date. The 200-pound gypsum treatment showed a decrease of 321 pounds of $CaCO_3$ in lime requirement when compared with the check. The 2000-pound gypsum treatment showed an increased lime requirement over the check amounting to 554 pounds of $CaCO_3$. This amount would indicate a slight acidity caused by the gypsum, but the average of the four determinations for the 2000-pound treatment is only a little over half this amount. While the lime requirements of the variously treated pots do not agree very closely at each sampling, there is a rather close agreement for the average. The gypsum treatments up to and including 1000 pounds per acre show practically the same lime requirement as the check pot. There is an increase of 243 pounds of $CaCO_3$ in lime requirement for the 2000-pound gypsum treatment over the check pot, which would indicate a slight increase in acidity if the method was accurate to 100

pounds of $CaCO_3$ per acre, but when the accuracy is really about 400 pounds no increase in acidity can be concluded.

Before treatment the neutral soil showed no lime requirement by the Tacke test. After treatment the check soil showed a lime requirement of 250 pounds. The pots receiving 100 and 200 pounds of gypsum showed a smaller lime

TABLE 2

Lime requirement by the Tacke method of three soils treated with different amounts of gypsum

Acid soil

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED				AVERAGE
		March 18	June 18	November 17	January 10	
		lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*
1	Check.....	2278	3183	3271	3270	3000
2	Gypsum 100 lbs.....	2570	3271	3037	3066	2986
3	Gypsum 200 lbs.....	1957	3154	3592	3416	3029
4	Gypsum 500 lbs.....	2480	3271	3592	3153	3124
5	Gypsum 1000 lbs....	2366	3329	3388	3550	3158
6	Gypsum 2000 lbs....	2832	3329	3329	3601	3243

Neutral soil

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED			AVERAGE
		March 17	June 16	November 15	
		lbs.	*lbs.*	*lbs.*	*lbs.*
1	Check.....	390	90	270	250
2	Gypsum 100 lbs.....	330	150	60	180
3	Gypsum 200 lbs.....	Alkali	60	Alkali	20
4	Gypsum 500 lbs.....	120	420	600	380
5	Gypsum 1000 lbs.....	540	180	330	350
6	Gypsum 2000 lbs.....	330	390	480	400

Basic soil

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED		
		March 19	June 24	November 24
1	Check,.....	Trace	Alkali	Alkali
2	Gypsum 100 lbs.....	Trace	Trace	Alkali
3	Gypsum 200 lbs.....	Alkali	Alkali	Alkali
4	Gypsum 500 lbs.....	Alkali	Alkali	Trace
5	Gypsum 1000 lbs.....	Alkali	Alkali	Trace
6	Gypsum 2000 lbs.....	Alkali	Alkali	Alkali

requirement than the check pot, but the pots receiving 500, 1000, and 2000 pounds of gypsum showed increases in lime requirement over the check, amounting to 130, 100, and 150 pounds of calcium carbonate, respectively. These amounts, however, are too small to permit the conclusion that gypsum has any effect on acidity, since differences as much as 400 pounds of $CaCO_3$ could be within the limit of experimental error.

It would not be expected to get a lime requirement by the Tacke method on the untreated basic soil, but determinations were made along with the acid and neutral soil to see if the gypsum would cause sufficient acidity to show a lime requirement on this soil. In nearly every case an alkaline reaction was obtained but several tests show a trace of a lime requirement. It would appear from the results by the Tacke method shown in table 1 that gypsum had no effect on soil reaction, regardless of whether the soil was acid, neutral, or basic.

To determine the effect of gypsum on the soil reaction, samples were taken from the pots in experiment 1 in 3 days, 10 days, 30 days, 5 months and 10 months after treatment for the determination of the hydrogen-ion concentration by the hydrogen electrode. The results for the three soils are summarized in table 3. The results are expressed in terms of pH values to simplify comparison. Each figure in the table represents the average of two determinations checking within 8 millivolts.

From a study of table 3 it will be noted that there is a striking uniformity in the results reported for the different samplings, and therefore in discussing these data only the average of the five determinations will be considered.

The first four treatments of the acid soil, including the check, showed an average pH value of 5.5 indicating no production of acidity due to applications of gypsum to 500 pounds per acre. The 1000-pound gypsum treatments showed an increase in acidity of 0.21 pH over the check, and the 2000-pound treatment showed an increase of 0.28 pH. Since the apparatus used for these determinations was accurate to 0.05 pH, these differences noted are large enough to conclude that gypsum does produce very slight acidity in an acid soil when applied at the rate of 1000 or 2000 pounds per acre. Comparing the 1000-pound gypsum treatment with the 2000 pounds we note the amount of acidity produced was not in proportion to the amount of gypsum applied.

The average of the first four treatments of the neutral soil showed almost identical pH values. The last two treatments, 1000 and 2000 pounds of gypsum, showed slight increases in acidity over the check of 0.14 pH and 0.27 pH, respectively. In the case of the neutral soil the amount of acidity caused by the 1000-pound treatment with gypsum was smaller by 0.07 pH than the same treatment of the acid soil. The same amount of acidity was produced by the 2000-pound gypsum treatment in both the acid and neutral soils. The acidity of the 2000-pound treatment of the neutral soil is just twice that of the 1000-pound treatment, showing that the increase in acidity was directly proportional to the amount of gypsum added. This was not true with the acid soil.

The average pH values were the same for the first four treatments for the basis soil. The 1000-pound gypsum treatment showed an increase in acidity of only 0.09 pH, and the 2000-pound treatment showed an increase of only 0.12 pH as compared with the check. Thus the pH values for the 1000 and the 2000-pound treatments were approximately the same, since the 0.03

pH difference is within the limit of experimental error. There being a difference of only 0.09 pH between the check and the 1000-pound treatment, it is safe to conclude that the heavier applications of 1000 and 2000 pounds of gypsum are less apt to cause acidity in a basic soil than they are in an acid soil or a neutral soil.

TABLE 3

Hydrogen-ion concentration of three soils treated with different amounts of gypsum

Acid soil

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED					AVERAGE
		March 6	March 13	March 26	August 6	January 5	
		pH	*pH*	*pH*	*pH*	*pH*	*pH*
1	Check	5.69	5.68	5.57	5.35	5.47	5.55
2	Gypsum 100 lbs.	5.78	5.64	5.52	5.29	5.30	5.50
3	Gypsum 200 lbs.	5.56	5.66	5.51	5.35	5.30	5.47
4	Gypsum 500 lbs.	5.52	5.63	5.52	5.35	5.44	5.49
5	Gypsum 1000 lbs.	5.35	5.52	5.46	5.20	5.19	5.34
6	Gypsum 2000 lbs.	5.29	5.35	5.32	5.19	5.19	5.27

Neutral soil

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED					AVERAGE
		March 6	March 12	March 25	August 5	January 6	
		pH	*pH*	*pH*	*pH*	*pH*	*pH*
1	Check	7.06	7.05	6.96	7.05	7.15	7.05
2	Gypsum 100 lbs.	7.03	7.03	6.98	7.05	7.06	7.03
3	Gypsum 200 lbs.	7.03	6.99	6.91	7.03	6.98	6.99
4	Gypsum 500 lbs.	6.96	7.01	6.91	6.99	7.05	6.98
5	Gypsum 1000 lbs.	6.88	6.88	6.89	6.94	6.99	6.91
6	Gypsum 2000 lbs.	6.71	6.72	6.71	6.88	6.88	6.78

Basic soil

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED					AVERAGE
		March 7	March 15	March 27	August 7	January 7	
		pH	*pH*	*pH*	*pH*	*pH*	*pH*
1	Check	7.89	8.03	8.01	8.04	8.04	8.00
2	Gypsum 100 lbs.	7.87	7.92	8.01	8.04	8.18	8.00
3	Gypsum 200 lbs.	7.89	7.92	8.01	8.03	8.04	7.98
4	Gypsum 500 lbs.	7.89	7.98	7.89	7.99	8.06	7.96
5	Gypsum 1000 lbs.	7.76	7.82	7.89	8.01	8.06	7.91
6	Gypsum 2000 lbs.	7.76	7.86	7.76	7.89	8.04	7.88

It is interesting to note in the case of the acid soil that the hydrogen-ion concentration for the check soil remained almost constant for the first month after the experiment was started. Five months later there was a slight increase in acidity amounting to a little over 0.2 pH. Also, with the pots treated with gypsum there was the same tendency for a constant hydrogen-ion con-

centration for the first month after treatment, and 5 months later a development of acidity. These data would indicate that the soil organisms were active during the continuance of the experiment and were able to aid in any possible chemical reaction with the gypsum and other soil constituents.

To summarize the results of table 3, it may be concluded that gypsum applied in amounts up to and including 500 pounds per acre does not increase or decrease the hydrogen-ion concentration of an acid soil, a neutral soil, or a basic soil high in calcium bicarbonate. When gypsum is applied in amounts as high as 1000 and 2000 pounds per acre there is a slight increase in hydrogen-ion concentration of an acid soil and a neutral soil, but the increase is very slight in the basic soil. These treatments, however, are much larger applications than are used under actual field conditions.

Experiment II

Experiment II was planned to determine the effect of gypsum on the reaction of a neutral soil treated with calicium carbonate and hydrochloric acid to give different degrees of acidity.

The soils in this experiment were sampled at three different times and tested for their lime requirement. The results of these tests, expressed in pounds of $CaCO_3$ per acre, appear in table 4. Determinations were made in duplicate for each treatment and each figure in the table represents the average of four determinations.

Considering first the data presented in table 4 for the neutral soil with and without gypsum, it will be noted that each test showed an increased lime requirement for the gypsum treatment over the untreated soil. The average lime requirement for the gypsum treatment in excess of the untreated soil, however, was only 230 pounds of $CaCO_3$ per acre, which is too small an amount to consider important, because the range of the experimental error for the method was 400 pounds of $CaCO_3$ per acre.

The soil treated with calcium carbonate showed a trace of lime requirement with and without the gypsum. This statement is in accord with the conclusion drawn from the effect of gypsum on the basic soil used in experiment I.

The soil treated with hydrochloric acid to make a 2-ton lime requirement also showed an increased lime requirement for the gypsum treatment in excess of the untreated soil. In the case of the test made on August 14, the gypsum treatment showed a lime requirement of 765 pounds of $CaCO_3$ in excess of the untreated soil, but the average lime requirement for the three tests in excess of the untreated soil was 370 pounds of $CaCO_3$, which also is within the 400 pound limit.

The soil treated with hydrochloric acid to make a 4-ton lime requirement showed an average lime requirement of 280 pounds of $CaCO_3$ for the gypsum treatment in excess of the soil without gypsum. This amount likewise is not sufficient to justify the claim that any production of acidity was due to the presence of gypsum.

The residual limestone was determined in the soils of experiment II to note whether the production of acidity caused by the gypsum would decrease the amount of carbonates present in the soil. The average results of the three determinations are included in table 4. Comparing the results of the lime-requirement tests with those of the residual limestone, we see in each case, except one, that where there is an increase in lime-requirement, apparently due to the gypsum, there is a gain in residual limestone. But these differences, as in the case of the average lime-requirement tests, are very small and well within the limit of experimental error. They do show, however, that the apparent acidity caused by the gypsum does not decrease the supply of soil carbonates, and this fact would indicate that gypsum does not increase the acidity.

TABLE 4

Lime requirement by the Tacke method and residual limestone of a neutral soil treated to vary in different degrees of acidity

POT NUMBER	TREATMENT PER ACRE	LIME REQUIREMENTS			AVERAGE	
		August 4	August 14	December 1	Lime requirement	Residual carbonates
1– 2	Check, (neutral soil)	375	315	15	235	1496
3– 4	Gypsum, 500 lbs.	810	450	135	465	1633
5– 6	$CaCO_3$, 4000 lbs.	Trace	Trace	Trace		4829
7– 8	$CaCO_3$, 4000 lbs., plus gypsum, 500 lbs.	Trace	Trace	Trace		4886
9–10	HCl equivalent to 2 tons lime requirement.	1965	1500	915	1460	1533
11–12	HCl equivalent to 2 tons lime requirement plus gypsum, 500 lbs.	2220	2265	1005	1830	1833
13–14	HCl equivalent to 4 tons lime requirement.	3990	5085	2100	3725	1346
15–16	HCl equivalent to 4 tons lime requirement plus gypsum, 500 lbs.	4170	6120	1725	4005	1276

It seems strange to have a lime requirement of varying amounts up to 4000 pounds of $CaCO_3$ per acre and still have residual limestone present. This condition may possibly be explained by the nature of the methods involved and the particular soil which was used in this experiment. This neutral soil undoubtedly contained small particles of limestone, the outer surfaces of which were hard and weathered, which caused them to be more or less resistant to the reaction that takes place in the lime-requirement determination. On the other hand, the constant agitation of the soil with the phosphoric acid, as used in the determination of carbonates, would permit the complete decomposition of all limestone particles and hence show residual carbonates present.

It will be seen also from table 4, that residual carbonates were found even in the soils treated with hydrochloric acid to make a 2-ton and 4-ton lime requirement. The amount of carbonates present in the soil with the 2-ton lime requirement was practically the same as reported for the untreated soil. But

the amount of carbonates present in the soil with the 4-ton lime requirement is smaller by 200 pounds of $CaCO_3$ per acre than the soil with the 2-ton lime requirement. This would indicate that the weak dilution of acid used for the 2-ton lime requirement treatment was not strong enough to decompose the limestone particles of the soil, and that the 4-ton requirement treatment was sufficient to decompose them only slightly.

Samples were drawn at three different times from the soils in experiment II and determinations made for hydrogen-ion concentrations. The results, expressed in terms of pH values, are given in Table V. Duplicate determinations were made of the soil in each pot, thus each figure in the table represents the average of four determinations.

A study of table 5 shows that the 500-pound treatment with gypsum for the neutral soil had the same average hydrogen-ion concentration as the

TABLE 5

Hydrogen-ion concentration of a neutral soil treated to varying degrees of acidity

POT NUMBER	TREATMENT PER ACRE	DATE SAMPLED			AVERAGE
		August 2	August 16	December 13	
		pH	*pH*	*pH*	*pH*
1– 2	Check (neutral soil)	7.05	7.54	7.02	7.20
3– 4	Gypsum, 500 lbs.	7.05	7.45	7.05	7.18
5– 6	$CaCO_3$, 4000 lbs.	7.38	7.89	7.54	7.60
7– 8	$CaCO_3$, 4000 lbs.; plus gypsum, 500 lbs.	7.39	7.81	7.47	7.58
9–10	HCl equivalent to 2 tons lime requirement	5.50	4.47	6.27	5.41
11–12	HCl equivalent to 2 tons lime requirement plus gypsum, 500 lbs.	5.63	4.85	6.22	5.56
13–14	HCl equivalent to 4 tons lime requirement	4.87	3.85	5.70	4.80
15–16	HCl equivalent to 4 tons lime requirement plus gypsum, 500 lbs.	4.67	4.13	5.80	4.86

same soil without gypsum. This condition was also true with the soil treated with 4000 pounds of $CaCO_3$ per acre.

Considering next the soil treated with hydrochloric acid to make a 2-ton lime requirement, we see that the determinations at each sampling for the soil with and without gypsum do not agree very closely. The average pH value of the three determinations for the soil without gypsum was 5.41, while the soil with gypsum showed an average pH value of 5.56. This showed a decrease in acidity amounting to 0.15 pH value for the gypsum treatment as compared with the soil without gypsum. However, this variation is not in agreement with the other soils under consideration, and because of the large differences obtained with different samplings, it cannot be concluded that gypsum decreased the acidity in this soil.

The soil treated with hydrochloric acid to make a 4-ton lime requirement also showed wide variations in pH values at different samplings. The first determination showed that the gypsum treatment increased the acidity

amounting to 0.2 pH as compared with the soil without gypsum. The next determination showed the reverse to be true. In this case gypsum decreased the acidity amounting to 0.28 pH. In the third determination the gypsum again showed a small decrease in acidity compared with the soil without gypsum. The average pH values of the three determinations were practically the same for the soil with and without gypsum.

It may be concluded from the results shown in table 5 that gypsum applied at the rate of 500 pounds per acre does not have any effect on the hydrogen-ion concentration of a neutral soil treated so as to vary in degrees of acidity.

While the results here reported are from laboratory experiments it is probable that they would apply in their essential points to field conditions. The writer has under way actual field experiments on several soil types in Iowa, and a study is being made to determine the effect of gypsum on soil reaction in the field. These results will be reported later.

COMPARISON OF RESULTS BY THE TACKE LIME REQUIREMENT METHOD WITH HYDROGEN-ION DETERMINATIONS

From the data presented in these experiments an opportunity is taken at this point to make a comparison of the results by the Tacke method with the hydrogen-ion determinations. By referring to tables 2 and 3 it will be noted in the case of the neutral soil that the average lime requirement for the first four treatments, including the check, was 207 pounds of $CaCO_3$ per acre, and the average hydrogen-ion concentrations of the same treatments with the same soil was 7.0 pH. The neutral point for the hydrogen-ion determinations in this work was 7.0 pH, while the neutral point for the Tacke method was from 0 to 400 pounds of $CaCO_3$ per acre. Thus a close correlation exists between the neutral points of the respective methods. No attempt was made to determine the lime requirement in this work by the hydrogen electrode, and consequently any further comparisons of the methods would be inconclusive and misleading because of different soil types and soil conditions.

CONCLUSIONS

1. Gypsum added in amounts from 100 to 2000 pounds per acre to an acid soil, a neutral soil, and a basic soil, did not increase or correct the acidity of the soil as shown by the Tacke lime-requirement method.

2. Gypsum applied at the rate of 100, 200, and 500 pounds per acre did not raise or lower the hydrogen-ion concentration of the soil as measured by the hydrogen electrode.

3. Excessive amounts of 1000 and 2000 pounds of gypsum per acre showed increases in acidity by the hydrogen electrode amounting to 0.21 pH and 0.28 pH, respectively, for the acid soil studied; 0.14 pH and 0.27 pH, respectively, or the neutral soil studied; and 0.09 pH and 0.12 pH, respectively, for the basic soil.

4. Gypsum applied at the rate of 500 pounds per acre to a neutral soil made to vary in degrees of acidity by additions of HCl and $CaCO_3$ had no effect on the hydrogen-ion concentration of the soil, and did not show sufficient lime requirement by the Tacke method to permit of the conclusion that gypsum had any effect on acidity.

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EXPERIMENTS WITH COMMON ROCK SALT: I. EFFECT ON ASPARAGUS[1]

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Sodium chloride or its elements are present in almost all plants. It does not necessarily follow, however, that one of these elements is necessary, or even of value, to the plants. Investigators differ as to the value of common rock salt as a fertilizer for various agricultural crops. Salt in excess is injurious to plant growth and stops germination of the seed, but all plants and all seeds are not affected to the same extent by the action of salt. Some are easily injured by the application of salt, and when such a plant is noxious, salt may be made use of for its eradication.

EARLIER EXPERIMENTS WITH ASPARAGUS

Salt has long been considered one of the essential fertilizers in asparagus growing. With few exceptions the older books on practical gardening recommend a liberal use of salt. The greatest benefit was claimed to be on old plantings. This seems to correlate with the experiments recorded below. White (10) recommended a top-dressing of 2 pounds of salt to the square yard before growth had commenced, and Burr (2) advised the application of 2 quarts to the square yard. Brill (1) says, "Coarse salt may be used after the third year at the rate of 5 bushels to the acre along the rows, or three times this amount if sown broadcast." Oemler (6) says that ". . . . the natural habitat of asparagus being the seacoast, it is benefited by applications of common salt, which may be used in sufficient quantities to destroy weeds, particularly if the crop is some distance from the seashore." Rawson (7) recommends salt as "an excellent thing to apply for a dressing, for, although it does not act as a manure, it is a great help in keeping down weeds." Landreth (5) states that "20 bushels of salt to the acre may be used to advantage annually; 5 bushels to the acre stimulates the asparagus, which is a salt plant, and retards weeds." Hunn and Bailey (4) say that the practice of sowing salt on asparagus is almost universal. However, they found that beds which had never received a pound of salt were as productive as those which had received an annual dressing. Nevertheless, they recommend a salt dressing. Recent works on gardening either make no mention of salt

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in connection with asparagus growing, or express doubt about beneficial effects. Card (3), in reporting some experiments with asparagus and salt, says, "Salt has no beneficial effect and is injurious when used in considerable quantities." The results obtained by Walker (9) with five varieties of asparagus ". . . . showed a decided difference in favor of the salted area amounting to 13.5 per cent, or a difference of 103.32 pounds per acre for the planting in its third year. The difference was not confined to the spring growth. There was an increased vigor manifest throughout the summer, and furthermore a noticeably increased glaucous appearance in the salt plants." The application of salt, broadcasted at the rate of 1,000 pounds per acre, was given the previous summer.

EXPERIMENTAL WORK

The experiments reported herein were conducted on the horticultural farm at the New Jersey Agricultural Experiment Station. Plots were laid out in the middle of two fields on which asparagus had been growing for 2 years and 11 years, respectively. These fields, and subsequently the experimental plots, consisted of an equal number of rows running east and west. The younger plants stood 20 inches in the rows, with the rows 2 feet apart, while the older plants stood approximately 2 feet in the rows with the rows 3 feet apart. The area is level, and the soil is a Sassafras loam. The following diagram shows the experimental plots running in duplicate, and the applications of salt that were made.

PLANTS 2 YEARS OLD				PLANTS 11 YEARS OLD			
Check	150 lbs.	300 lbs.	500 lbs.	Check	150 lbs.	300 lbs.	500 lbs.
500 lbs.	300 lbs.	150 lbs.	Check	500 lbs.	300 lbs.	150 lbs.	Check

In addition to approximately 8 tons of cow manure and 4 tons of poultry manure the salt applications were made on the plots on the rows April 17, 1919, after a heavy rain. On April 13, 1920, salt was again applied, in addition to 8 tons of cow manure and 5 tons of poultry manure. The weather was rainy. Rainfall for the months April to September, 1919, at New Brunswick was 29.79 inches, and for the whole year was 52.41 inches, while the normal precipitation is about 45 inches.

From the younger beds but two cuttings were made, April 26 and May 2, 1919. From the older beds cuttings were made throughout the entire season from April 26 to June 18, 1919. The average weight per plant for the two plants is recorded in table 1.

As may be seen from these figures, the beds were quite uniform. The influence of the salt on the production of the stalks harvested can be considered as *nil*.

When the harvesting of the stalks ceases, a tall bushy growth develops which enables the plant to make greater use of the plant-food in the soil and store it up in the roots for stalk production the following season. The condition and vigor of the fall growth, therefore, has a direct bearing upon the yield and size of the stalks of the next season. In view of this growth as food storage, countings of plants and stems, and measurements of the latter,

TABLE 1

Average total weight of cuttings per plant of asparagus treated with salt

TREATMENT PER ACRE	YOUNG PLANTS	OLD PLANTS
lbs.	*gm.*	*gm.*
None	12.1	445
150	13.2	457
300	12.4	442
500	12.8	451

TABLE 2

Average number of stems, total length of stems, and average length of stems per plant, for two corresponding plots of 2-year-old asparagus plants

MEASUREMENTS		CHECKS			150 POUNDS OF SALT			300 POUNDS OF SALT			500 POUNDS OF SALT		
Number	Date	Number of stems	Total length of stems	Average length of stems	Number of stems	Total length of stems	Average length of stems	Number of stems	Total length of stems	Average length of stems	Number of stems	Total length of stems	Average length of stems
			cm.	*cm.*		*cm.*	*cm.*		*cm.*	*cm.*		*cm.*	*cm.*
1	May 9	1.30	48.5	36.0	1.33	47.0	37.0	1.45	52.0	35.0	1.30	42.0	33.0
2	May 16	1.89	90.0	42.5	1.87	75.0	38.5	2.47	103.0	40.5	2.13	82.0	40.5
3	May 23	2.07	152.0	68.5	2.40	159.0	60.5	2.52	152.0	65.0	2.66	153.0	61.0
4	May 29	2.12	194.0	91.5	2.79	212.0	84.5	2.98	258.0	84.5	3.08	215.0	83.5
5	June 7	2.27	220.0	97.0	2.51	238.0	96.0	3.20	292.0	94.0	3.16	306.0	100.5
6	June 14	2.29	231.0	99.0	2.61	248.0	96.0	3.33	300.0	99.0	3.44	313.0	95.5
7	June 21	2.46	236.0	93.5	2.64	251.0	93.0	3.42	312 0	90.0	3.58	321.0	90.0
8	June 29	2.90	248.0	87.7	2.90	256.0	84.9	3.79	338.0	87.6	3.89	339 0	86.3
9	July 5	3.21	275.0	86.0	3.35	284.0	84.0	4.00	345.0	79.0	4.36	350.0	82.5
10	July 12	4.04	307.0	75.8	4.04	373.0	91.2	4.79	395.0	79.6	5.0	426.0	85.1
11	August 2	4.87			5.28			5.97			6.31		
12	August 23	5.73			5.97			6.57			6.88		
13	September 6	5.88			6.05			6.83			7.46		
Per cent increase.....					2.9	18.2		16.2	28.6		26.8	38.7	

were taken throughout the entire season, at intervals of from 7 to 10 days. An attempt was made to measure the thickness of the stalks, but was discontinued after these measurements had been correlated with the height of the stems. The average number of stems per plant, the total height of plants, and length of stems for the two corresponding plots of young plants are given in table 2. Counting and measuring was begun 7 days after the last cutting.

During the second half of the growing season the asparagus beetle did some damage which resulted in dead tips of the stalks.

The figures in table 2 show clearly the regular increase in the number of stems per plant and the corresponding total length of stems per plant, while the average length of the stems per plant reached a maximum in the middle of the season. Sprouts which appeared later in the season could not develop such a vigor as to reach the maximum height of the first stalks. The number of stems and the total length of stems per plant increased regularly in all series; but where applications of 300 and 500 pounds of salt per acre were made, the number of stems, and consequently the total length, was considerably greater at the tenth measuring than that of the plants growing on the plots where 150 pounds of salt were applied. The average number of stems per plant on these plots were, respectively, 18.5 and 23.7 per cent greater than the average number of stems of the plants on the check plots. The total length per plant on these plots showed still greater differences, namely, 28.6 and 38.7 per cent more than the total length of the stems per plant on the check plots. Later in the season accurate measuring became extremely difficult on account of the entangling of the branches, but counting was continued though at greater intervals. At the end of the season, just before harrowing, the average number of stems of the plants on the plots which received respectively 150, 300 and 500 pounds of salt per acre in addition to the manure, as compared with the average number of stems on the check plots, showed an increase of 2.9, 16.2, and 26.8 per cent in the order named.

Countings and measurements also were made on the old plants but the measuring had to be discontinued later on. The entangling of the stem became so great that accurate measuring was impossible. Stems and plants were counted as usual. The average length of the stems in the earlier part of the growing season followed closely the number of stems, as was the case for the younger plants. According to observations made on July 25, August 10, and September 6, no difference in height could be seen though growth was probably more dense. The plants looked healthy on all plots until August 25 when the color of the plants began to change somewhat, on account of the advance of the season. On September 8 a number of plants showed yellowness and dried tips.

Three weeks after the last cutting was made the counting of the stems was begun, and was continued until September 6. The compiled data of the average number of stems per plant for the two corresponding plots are given in table 3.

The increase in top growth of the plants was regular on all plots. The number of stems at the beginning of the counting was the highest on the plots to which 500 pounds of salt was applied, and remained so until the end of the season. The number of stems at the end of the season was 2.1, 11.7, and 25.9 per cent over the check plots, for applications of 150, 300, and 500 pounds of salt per acre, respectively. These results were much more pro-

nounced than was expected. The average percentage of increase of the number of stems for the 2-year-old plants was very much the same as the average percentage of 11-year-old plants on all plots. They are given here with emphasis on the fact that they represent only a single season of countings.

The average weight per plant obtained by the cuttings of the young and of the old plants during the season of 1920 is given in table 4, together with the number of stalks graded according to the commercial way for marketing, which indicates the market value of the product as good, fair and poor stalks.

TABLE 3

Average number of stems per plant for two corresponding plots of 11-year-old asparagus plants in 1919

COUNTINGS MADE		NO TREATMENT	150 POUNDS SALT	300 POUNDS SALT	500 POUNDS SALT
Number	Date				
1	July 12	8.50	8.69	10.42	11.72
2	July 25	12.29	12.58	14.57	15.87
3	August 1	14.01	14.49	16.35	18.14
4	August 12	14.66	14.83	16.62	18.35
5	August 23	14.95	14.99	16.88	18.65
6	September 6	15.29	15.62	17.08	19.22
Per cent increase.....			2.1	11.7	25.9

TABLE 4

*Average weight per plant of stalks of asparagus cut during the season of 1920 and grades of stalks**

TREATMENT PER ACRE	YOUNG PLANTS					OLD PLANTS				
	Weight per plant	Increase over check	Grades			Weight per plant	Increase over check	Grades		
			Good	Fair	Poor			Good	Fair	Poor
lbs.	*gm.*	*per cent*				*gm.*	*per cent*			
Checks	149.7		72	33	28	478.7		158	60	55
150	146.3	−2.3	76	31	23	460.8	−3.7	130	63	77
300	157.5	5.3	75	33	29	490.0	2.4	141	64	89
500	175.4	17.1	81	25	45	535.4	11.7	181	79	109

* During the absence of the writer in the season of 1920 Prof. L. G. Schermerhorn of the Department of Horticulture took records on the counting and grading of the stalks. For this help the writer acknowledges his indebtedness.

Unfortunately, not all of the stalks were counted and graded throughout the season. The figures given are therefore only an indication of the direction in which the increase in weight seems to go.

A striking increase in weight per plant was obtained by the heaviest applications of salt, as compared with the plants from the check plots. The total weight of stalks produced by the old plants which received 500 pounds of salt per acre was 11.7 per cent higher than the total weight of stalks per plant produced on the check plots, and the total weight of stalks per plant of the

young plants grown on the plots receiving the same amount of salt per acre increased 17.1 per cent over the weight of stalks on the check plots. The total weight of stalks per plant from the plots receiving 300 pounds of salt was but slightly higher than the total weight produced on the check plots, both for old and for young plants, while the total weight of stalks per plant on the plots with applications of 150 pounds per acre was slightly below the total amount per plant on the check plots.

As may be seen from the available data for the cuttings during the first 24 days of the season, the increase in numbers was mainly in the poor grade. This is true both for the young plants and for the old plants. The number of poor stalks for the old plants on the check plots during this period was 20.1 per cent, while 29.5 per cent of the stalks grown on the plots which received 500 pounds of salt were of a poor grade. A similar grading and counting for the young stalks showed that 21 per cent of the stalks grown on the check plots, and 29.9 percent of the stalks from the plots which received the heaviest salt applications, were of a poor grade. These figures seem to indicate that much of the increase in weight can be found in an increase of poor-grade stalks; however, since this grading and counting is incomplete, no definite conclusion can be drawn. Besides, poor-grade stalks are usually thin, and their increase under the influence of the salt might be explained by the production of new stalks which, the following year, will produce a product of better grade.

The average weight per plant checks in general very closely with the countings of the stems and the height per plant of the previous summer. Keeping in mind the fact that the measurements and the cuttings represent only one year's work, it seems that the growth of asparagus is stimulated by salt. This conclusion seems to be justified also by the fact that the yield of the previous season was quite uniform. Earlier investigators accredited the beneficial effects of salt mainly to its ability to prevent the growth of weeds. The applications of salt in this case were entirely insufficient for such a purpose, for weeds grew as fast on the treated plots as on the untreated plots. From our work in the eradication of weeds by means of salt, it is known to us that far more than 500 pounds per acre is needed to prevent the growth of weeds. Besides, all plots with and without salt were kept fairly clean while measurements were taken. It appears therefore that there is a beneficial action of the salt itself on the growth and yield of asparagus grown on this particular soil. Asparagus can stand an extraordinary amount of salt, as is recorded elsewhere (8).

SUMMARY

Experiments with a top-dressing of sodium chloride, in addition to manure, were made upon 2-year-old and 11-year-old asparagus plants. Applications of common rock salt (Retsof agricultural salt) were made at the rate of 150, 300 and 500 pounds per acre. Cuttings were made the same season. Throughout the growing season following this cutting the stems of the plants were counted and the length measured at intervals of from 7 to 10 days.

The following spring the same amounts of salt were again applied, and the stalkscut. The stalks were weighed, counted, and graded for market purposes.

The number of stems and the total length of plants increased regularly in all series, the stems reaching their maximum height in the middle of the growing season.

At the last measurement taken, the average total lengths per plant of the 2-year-old asparagus plants on the plots receiving 150, 300 and 500 pounds of salt per acre were, respectively, 21.1, 28.6, and 38.7 per cent greater than the average lengths of plants on the check plots.

The counting of the stems was continued until September 6 and the increase in the average number of stems for the plots receiving 150, 300 and 500 pounds of salt per acre was found to be 2.9, 16.2 and 26.8 per cent, as compared with the check plots.

The average number of stems per plant on the 11-year-old plants increased 2.1, 11.7 and 25.9 per cent for applications of 150, 300 and 500 pounds of salt per acre, over the check plots.

The average weight of stalks per plant obtained the following year was increased for the young plants grown on plots receiving 300 and 500 pounds of salt per acre, by 5.3 and 17.1 per cent, respectively. For the old plants an increase of 2.4 and 11.7 per cent was observed. The production of the plants which received applications of 150 pounds of salt per acre decreased 2.3 per cent for the young plants and 3.7 per cent for the old plants, as compared with the average weight per plant on the check plots.

The increase in the number of stalks produced, and consequently in weight, seems to lie in the direction of the poorer grades. Emphasis is laid on the fact that the work represents only 2 years of cutting and 1 year of counting and measuring.

Asparagus grown on this soil seemed to be stimulated directly by the salt applications, for weeds were kept down by hand on all plots throughout the growing season.

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EXPERIMENTS WITH COMMON ROCK SALT: II. ERADICATION OF WEEDS AND CLEANING OF ROADSIDES WITH SALT[1]

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INTRODUCTION

The cleaning of roadsides and the eradication of weeds, with the progress of intense cultivation, becomes a problem which attracts more and more attention. Many attempts have been made to supplement the mechanical means of eradication of weeds and light underbrush by more rapid chemical methods. Salt is one of these means which can be used in reducing weeds and brush. Experiments reported by a number of investigators agree on the effectiveness of salt for killing weeds, but usually do not agree on the manner in which this effect is brought about. Cox (4) states that for eradication of ferns salt is a better spray material than either arsenite of soda or iron sulfate. With ferns at an average degree of thickness on the land, 150 pounds of salt dissolved in 60 gallons or more of water to the acre is sufficient. Two sprayings a year are recommended. Cox (3) also states that 125 pounds of common salt in 50 gallons of water will control such weeds as dandelion, mustard and blueweed. Jones and Orton (8) experimented with salt on knotgrass (*Polygonum aviculare*) and some of the common grasses (*Panicum*). They obtained satisfactory results with 640 to 3200 pounds of salt per acre used in dry form. Jones (7) found salt to be "the best chemical yet tried for killing the orange hawkweed, and when properly used it is entirely effective. Salt should be applied on a hot sunny day, preferably during a period of dry weather, and broadcasted in amounts of from 1 to 1.5 tons per acre." Blackman (1) experimented for 40 years with the salting of Canada thistles. He found that applications of salt while the thistles are moist with dew or rain will kill both tops and roots in pasture and cultivated land. Field experiments at Harper Adams Agricultural College (5), however, indicate that thistles do not seem to respond to treatment with salt, as the effect of judicious cutting is not intensified. At the Kansas Agricultural Experimental Station (6) applications of from 3 to 20 tons of salt per acre were made on areas infested with bindweed. Ten tons per acre was deemed sufficient to kill the weed, provided the small spots where the weed grows up were resalted. Russel (9)

[1] Paper No. 40 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

found that a solution of 125 pounds of salt in 50 gallons of water was effective for the eradication of mustard. Brenchley (2) states that salt is good on grass-land; 500 to 600 pounds per acre applied in the spring at the time nettles are cut down will do much to prevent this weed from springing up again.

EXPERIMENTS IN 1919

The experiments reported below were conducted during the years of 1919 and 1920 on the College Farm at New Brunswick and along the roadsides near Riverton, New Jersey, in an area infested by the Japanese beetle. The weeds included pigweed (*Chenopodium album*), orach (*atriplex pátula*), ragweed (*Ambrosia trifida*), asparagus, dandelion, wild strawberry, hawkweed (*Hieracium aurantiacum*), knotgrass (*Polygonum aviculare*), ferns, and some of the common grasses and weeds which were not predominating. The shrubbery included poison ivy (*Rhus toxicodéndron* L.), five-leaved ivy (*Rhus radìcans*), sassafras, oak, wild cherry, grape vine, hackberry, blackberry, alder, raspberry, and ash.

The soil on the College Farm consists of Sassafras loam, while the soil at Riverton and Hartford is a light sandy loam.

Applications of the salt were made broadcast at New Brunswick and at Riverton, on the weeds and on and around the stumps of the shrubs. At Hartford the salt was applied broadcast on all plots, no effort being made to treat the stumps separately. The brush on the plots at Riverton had been cut for some time and burned on the place before the salt applications were made. No cutting was done at New Brunswick. The salt applications varied from 2 to 8 tons per acre, and the size of the plots varied from 650 to 1250 square feet.

The rainfall during the year 1919 at New Brunswick was 52.41 inches, while the precipitation during the months of the experiments was 5.31, 8.33, and 6.30 inches for June, July, and August, respectively. The treatment of the plots, the date of application, the meteorological conditions about the time of application and the kind and condition of the growth on the weed and shrub plots at New Brunswick on July 12, and August 29, 1919, are given in table 1.

Although much of the ground vegetation was killed by the smaller applications weeds survived and sprang up again in the late fall. Where the heavy applications were made, 90 per cent of the weeds were killed, the poison and five-leaved ivies were injured and partly killed, but pigweed was not affected at all.

Experiments with the object of killing poison ivy were made during 1919, and the after-effects of the salt on these plots in 1920 are recorded in table 2. No other vegetation than poison ivy was found on these plots, the ground being thickly covered with sprouts from 1 to 3 feet high sent out by the vines which had rooted at every notch. These branches were not cut before the salt dressing was made. The salt was applied broadcast.

TABLE 1

Condition of weeds and shrubs on salt-treated plots during 1919, on Sassafras loam soil

PLOT NUMBER	TREATMENT PER ACRE	DATE OF APPLICATION	METEOROLOGICAL CONDITIONS	KIND OF GROWTH	CONDITIONS JULY 12, 1919	CONDITIONS AUGUST 29, 1919
	tons					
1	2.0	June 13	Warm, sunny day after several days of dry weather; 2 days later a shower	Pigweed, poison ivy, five-leaved ivy, (3–5 feet) hackberry, ground vegetation thick grasses, wild strawberry	Ground vegetation affected, some weeds dead	Generally not much affected; 40 per cent of weeds killed
2	2.5	June 13	Same	Same	About the same as no. 1	About the same as no. 1; about 50 to 60 per cent of weeds killed
4	3.0	June 13	Same	Same	Ground vegetation strongly affected	Most weeds injured or killed; poison ivy injured
6	3.5	June 13	Same	Same	About the same as no. 4, more weeds dead	About the same as no. 4
8	4.5	June 13	Same	Same	Strongly affected, most weeds dead, hackberry seriously injured; small poison ivy dead; five-leaved ivy little affected	Ground vegetation mostly killed; larger poison ivy but slightly injured, making healthy new shoots; pig weed growing
10	5.0	June 13	Same	Same	About the same as no. 8, but five-leaved ivy more affected	About the same as no. 8, but poison ivy had not as many new shoots; pigweed growing; other weeds 90 per cent killed
3, 5, 7, 9	Checks		Same	Same	On all plots vigorous growth	All plots thickly covered by weeds, etc.

TABLE 2

Condition of salt-treated poison ivy plots during 1919 and 1920 (Sassafras loam)

PLOT NUMBER	TREATMENT PER ACRE	DATE OF APPLICATION	METEOROLOGICAL CONDITIONS	CONDITION JULY 12, 1919	CONDITION AUGUST 29, 1919	CONDITION OCTOBER 8, 1920
	tons					
1	3	6/13	Warm, sunny weather after several dry days; 2 days later a shower	Little effect	40 per cent injured	No effect to be seen
2	4	6/13	Same	Small plants affected	20 to 30 per cent killed; about 30 per cent injured	Partly killed; larger plants (only slightly injured) making healthy new shoots
4	6	6/13	Same	60 per cent killed or injured	Approximately 50 per cent killed; larger plants made great number of new shoots	About 60 per cent less growth as compared with check plot
6	8	6/13	Same	Mostly killed or injured	80 to 90 per cent killed; remainder badly injured; very few new tiny shoots	Very little growth
3–5	Checks	6/13	Same	Vigorous growth	Vigorous growth	Plots thickly covered

TABLE 3

Condition of weeds and shrubs on salt-treated plots near Riverton, N. J., during 1919 on a light sandy loam soil

PLOT NUMBER	TREATMENT PER ACRE	DATE OF APPLICATION	METEOROLOGICAL CONDITIONS	KIND OF GROWTH	CONDITION AUGUST 11, 1919	CONDITION SEPTEMBER 4, 1919
	tons					
1	3	6/28	Dry weather, night following rain	Sassafras, alderberry, oak, vine, pigweed, raspberry, fern	Not very effective, some small stumps killed*	Some stumps killed; fern, vine, pigweed growing*
2	4	6/28	Same	Same	Great number of small stumps killed; sassafras alive; ferns killed	Stumps nearly all killed except few sassafras; weeds growing again, probably reseeding; ferns killed
3	4	6/28	Same	Sassafras, alder, oak, vine, pigweed, poison ivy, five-leaved ivy, orach	Number of small stumps killed; vine, poison ivy, pigweed slightly affected	Many stumps killed; pigweed and orache growing vigorously; 30–40 per cent of ivy killed
4	5	6/28	Same	Same	More effective than no. 3; poison ivy started up again; vigorous growth of orach	Larger stumps all killed; some small stumps apparently not touched by the salt were growing; few stumps made slight growth but leaves had sickly appearance, curled, small and brown; pigweed and orach growing vigorously
5	3	6/28	Same	Pigweed, vine, blackberry, tall grasses	Most of grass and blackberry killed	Blackberry and grass killed; vine little affected, pigweed seemed stimulated

* Notes on all plots are made in comparison with check plots.

Poison ivy can stand very heavy applications of salt. Even with 8 tons of salt per acre, not all of the stems were killed. The injury to the plants on this plot was severe, however. In October, 1920, but little growth was on the ground, while the check plots were thickly covered. If farmers want to rid their roadsides around their houses and fields, salt seems to be an excellent killer. To prevent growth entirely a resalting should be made on plants which have survived the first application. The second application need not be so heavy as the first.

The experiments at Riverton were conducted on another soil type, and included more brush and ferns. All growth was cut and the brush burned before the salt applications were made. The total rainfall for the months of June, July, August and September was 18.83 inches at Philadelphia (about 10 miles away).

An application of 5 tons of salt per acre killed nearly all stumps of sassafras, alder and oak, while poison ivy and five-leaved ivy were only injured. Pigweed and orach were not affected but grew vigorously. These weeds seemed to be stimulated by the smaller applications. An application of 3 tons of salt per acre killed the hardy grasses and the blackberry, while grape vines were but little affected.

EXPERIMENTS IN 1920

Experiments near Hartford, N. J.,[2] were conducted during the months of May, June, July, August and September, 1920. Here an effort was made to determine not only the amounts of salt needed to kill the weeds and brush, but also the time of the year at which the best results can be obtained, the influence of cutting weeds and brush before or after salt applications in comparison with uncut growth with salt applications, and the kind of salt which is best for weed eradication.

The different kinds of salt included Kerr's agricultural salt, Retsof agricultural salt, and a fine table salt sent by the United States War Department. Kerr's agricultural salt is a rather coarse salt. The Retsof agricultural salt is coarse and has a high percentage of sodium chloride, analyses running from 96 to 98 per cent NaCl. The salt from the War Department was a common fine table salt, not so well adapted to the work as Kerr's and Retsof agricultural salt, as it was hard and lumpy. The lumps could be broken only with difficulty, and remained for a long time on the plots without being dissolved.

Growth on the plots included ragweed, pigweed, wild strawberry, asparagus, hardy grasses, poison ivy, five-leaved ivy, wild cherry, hackberry, sassafras, sumac, wild grape and raspberry. Some of the wild cherry and sassafras were 4 to 6 inches in diameter, while other growth was very dense. When the vegetation was cut, as indicated in the table, the cutting was done immediately after the salt was applied. Work was begun May 1, and was continued

[2] The writer is indebted to John J. Davis and C. H. Hadley, entomologists in charge of the Japanese beetle control work at Riverton, New Jersey, for supplying these data, and for their cordial help in carrying out the other experiments at Riverton.

throughout the summer, the last application being made September 13. In all experiments, rain followed the applications of the salt within a short time and probably no particular application received an appreciable advantage over the others. The rainfall at Philadelphia during the months April to October was 27.72 inches.

The plots were frequently examined and the condition of plots 1 to 23, inclusive, on September 13 is recorded in table 4. The plots were examined again on November 12, and the notes taken on plots 24 to 30 are included in the same table. No difference from the examination on September 13 was noticed on plots 1 to 23.

Applications of 3, 4 and 5 tons of salt per acre killed most of the ground vegetation, as shown by a comparison with the check plots. Some of the stumps of wild cherry, sassafras, and hackberry were killed, but most of these were thrifty; pigweed, ragweed, poison ivy, five-leaved ivy and asparagus were thrifty. Such applications are insufficient to kill deep-rooted plants, such as poison and five-leaved ivies, sassafras, wild grape, and wild cherry, but the effects can be seen on these and on other plants enough to show appreciably between treated and untreated plots. As a rule 5 to 6 tons of salt per acre are effective in killing noxious plants if conditions are favorable.

Salt applications of 8 tons per acre were very effective in killing. Occasionally an unusally thrifty grape, sassafras or wild cherry survived. The shoots of these plants had made but very slight growth when the plots were examined again on November 12. It was very remarkable that asparagus plants survived (after cutting) on all plots. Even the heaviest applications did not do much harm to these plants, and applications of 4 tons per acre seemed to stimulate growth.

The deep-rooted plants were killed with difficulty; especially grape, five-leaved ivy, poison ivy, wild cherry, hackberry, sumac and sassafras, in the order named. Pigweed and ragweed were apparently unaffected by the salt applications; applications of as much as 8 tons of salt to the acre did little injury to these plants. Sometimes they even seemed stimulated by the salt and made greater growth on the salted plots than on the check plots. It is possible that NaCl affects this soil in such a way that it is more favorable for the growth of these weeds; or it may be that, with competition for space eliminated, these weeds have a better chance. At any rate, their growth shows that their vital activities are not harmed.

General observations on these experiments show that salt applications made early in the season are effective for brush and stumps, but less effective for weeds, probably on account of reseeding. Salting in the fall has very little effect. This was shown by earlier experiments conducted near Pleasantville, New Jersey, with uncut oak shrubs. Little or no effect could be seen during the following spring. Salt applications there did not exceed 4 tons per acre; these results are corroborated at Hartford where applications of 4 tons of salt per acre were given. The effects of salt applications after mid-season are very noticeable, but salting at about mid-season is most effective.

TABLE 4

Cut and uncut weeds and brush treated with different kinds of salt applied in different amounts and at different times of the year near Hartford, N. J.

PLOT NUMBER	DATE OF APPLICATION	CUT OR UNCUT	KIND OF SALT	TREATMENT PER ACRE	METEOROLOGICAL CONDITIONS	CONDITION SEPTEMBER 13, 1920
				tons		
1	5/1	Cut	Kerr's agricultural	3.5	Rainy weather, temperature below normal	Pigweed, ragweed, poison ivy, asparagus, five-leaved ivy, wild cherry, all thrifty; hackberry, sassafras and sumac not very thrifty; hackberry leaves appear yellow spotted and deformed, resembling mosaic; grape foliage very small, scant, and unthrifty; apparently an appreciable number of stumps of wild cherry, sassafras, and hackberry did not come up; ground vegetation thin
2	5/1	Cut		Check	Same	Greater growth of sassafras and poison ivy; ground vegetation (grasses, ivy, etc.) noticeably heavier
3	5/11	Cut	Retsof agricultural	3.5	Rain in afternoon and following night	About the same as plot 1; sassafras probably less noticeably affected
4	5/11	Cut		Check	Same	About the same as plot 2
5	5/22	Cut	Same	3.5	Dry, sunny weather, rain 2 days later	About the same as plot 1
6	5/22	Cut	War department	3.5	Same	About the same as plot 1
7	5/22	Cut		Check	Same	Noticeably denser growth, not only the grass and ivy covering the ground but also a heavier growth of sassafras, wild cherry, etc.

8	6/10	Uncut	Retsof agricultural	4.0	Dry, sunny weather, next day shower	Two-thirds of sassafras stumps dead as well as many wild cherry stumps
9	6/10	Cut	Same	4.0	Same	No choice between this and plot 8
10	6/10	Uncut	War department	4.0	Same	About the same as plot 8; no apparent difference between plot 9 and this plot
11	6/10	Cut	Same	4.0	Same	Same as plot 10
12	6/10	Uncut		Check	Same	Ground vegetation vigorous; abundant growth of sassafras and poison ivy
13	7/7	Cut	Retsof agricultural	8.0	Heavy shower in evening	This plot showed best effects of all 1920 plots; absolutely everything dead except an occasional unthrifty grape or hackberry and a thrifty asparagus; all poison ivy killed
14	7/7	Uncut	Same	8.0	Same	Killed out completely raspberry, grass and all vegetation excepting wild cherry, grape and sassafras and these appreciably affected; all poison ivy and five-leaved ivy dead
15	7/7	Cut	Same	4.0	Same	Much of undergrowth, sassafras and vine killed; prickly ash (not occurring in above plots) less affected; apparently this treatment more effective than earlier plots where equal amounts of salt were applied; some wild cherry, sassafras and hackberry alive; most of poison ivy killed

TABLE 4—*Concluded*

PLOT NUMBER	DATE OF APPLICATION	CUT OR UNCUT	KIND OF SALT	TREATMENT PER ACRE	METEOROLOGICAL CONDITIONS	CONDITION SEPTEMBER 13, 1920
				tons		
16	7/7	Uncut	Same	4.0	Same	Not appreciably different from plot 15, except some growth of brush which might be expected as vegetation was uncut
17	7/7	Uncut		Check	Same	Heavy growth of vegetation; poison ivy abundant
18	8/5	Cut	Same	8.0	Dry weather, rained hard night following application	Not as complete a kill as in plot 13 but a fairly effective kill of vegetation; some poison ivy, five-leaved ivy, sumac and sassafras coming through; majority of vegetation killed off
19	8/5	Uncut	Same	8.0	Same	Not appreciably different from plot 18 except vegetation necessarily higher
20	8/5	Cut	Same	4.0	Same	Fairly effective in killing vegetation; noticeably not as effective as plot 13
21	8/5	Uncut	Same	4.0	Same	Not very effective
22	8/5	Cut		Check	Same	All growth started vigorously again
23	8/5	Uncut		Check	Same	Heavy growth of vegetation
						CONDITION NOVEMBER 12, 1920
24	10/13	Uncut	Retsof agricultural	4.0	Dry, sunny weather several days before rain	Not very effective; ground vegetation killed; some sassafras, sumac and hackberry injured, some killed
25	10/13	Cut	Same	4.0	Same	More effective than on plot 24, but apparently treated too late in season

26	10/13	Uncut		Check	Same	Vegetation thick
27	10/13	Uncut	Same	8.0	Same	Nearly everything killed, except some sassafras and poison ivy; much sassafras and poison ivy on this and plot 28
28	10/13	Cut	Same	8.0	Same	About same as plot 27
29	10/13	Uncut		Check	Same	Same as plot 26 but more sassafras and poison ivy
30	10/13	Cut		Check	Same	Stumps had made sprouts again

The plots on which the vegetation was cut just before or immediately after the applications of salt showed, in all cases, much better results than plots on which the high and rank vegetation was allowed to remain. There is, therefore no doubt about the effect of cutting when salt applications are made.

Some writers recommend applications of the salt in dry form, while others say that it should be applied in solution to procure the best results. The reason why investigators differ as to the effect of the salt as a weed-killer seems to lie in the fact that the action of NaCl upon the plants is not well understood. True (11) states that salt has slight toxic effects upon some plants but that most of its value as a weed-killer depends upon the fact that it rapidly draws the water out of the plant tissues with which it comes in contact. This view is still held by many workers. All of our experiments indicate that the injury is caused by the chlorine content taken up by the plant; at least far more than by the absorbing of water out of the plant tissues. Besides, the latter could be true only for weeds with broad, outstanding leaves, such that salt could remain on them for a considerable length of time. But the leaves of grasses are long, narrow, and upright, so that even moisture does not adhere to them for a long time. Cut or burnt weeds and stumps have but few, if any, leaves left, and dry salt could not be effective. The toxicity of chlorine is well known. In our experiments the best results were obtained when the salt was brought into solution by rain soon after the applications had been made; the salt, being dissociated, could then be taken up by the plants. Laboratory experiments showed that equivalent amounts of salt added to a sandy soil with 30 per cent of the optimum moisture content were not so effective as the salt applied to a sandy soil with an optimum moisture content, or 60 per cent of the water-holding capacity of the soil.

The flocculation of a soil is more pronounced when there is an excess of NaCl; thus settlement of the fine soil particles is more rapid. When NaCl is applied to pots, an impermeable crust is formed which, with the change in the structure of the soil, results in interference with the ordinary aeration of the soil. Freezing-point determinations of the salted soil extract showed in laboratory experiments that the osmotic concentration of the soil moisture became greater, preventing the roots of the plants from taking up unlimited amounts of water. If, therefore, lack of water was the cause of injury, the salt in the pots with 30 per cent of the optimum moisture content should be more active.

Great quantities of NaCl applied to a soil decrease plant growth on account of the toxic effects, but when washed away or leached out sufficiently, salt stimulates growth. When added in small quantities to asparagus it stimulates directly. It does not seem plausible that this stimulating effect is due to the sodium content, for in the experiments with asparagus, sufficient potassium seemed to be available. Since the experiments of Schulze (10) have shown quite conclusively that the effect of NaCl on liberating potassium is

not universally important, it seems safe to conclude that the Cl ion taken up in small quantities by the plant stimulates growth; but when absorbed in larger quantities, causes injury.

SUMMARY AND CONCLUSIONS

Experiments with sodium chloride for killing weeds and brush were conducted along roadsides on two different soil types in 1919 and 1920. Applications of from 2 to 8 tons of salt per acre were made.

At New Brunswick and Hartford the salt was broadcasted, while at Riverton the stumps of shrubbery were treated more severely.

The objects of the experiments were: to determine the necessary amounts of salt needed to kill weeds and brush; to learn at what time of the year best results can be obtained; to learn whether or not the cutting of weeds and brush before or after salt applications has influence on the effects; and to determine which kind of salt (fine or coarse) is best for these purposes. The different kinds of salt used were Kerr's agricultural salt, Retsof agricultural salt and ordinary table salt.

Plant growth observed in these experiments included pigweed, orach, ragweed, asparagus, dandelion, wild strawberry, hawkweed, knotgrass, ferns, hardy grasses, poison ivy, five-leaved ivy, sassafras, oak, wild cherry, wild grape, hackberry, blackberry, alder, raspberry, and ash.

The following tentative conclusions may be drawn:

1. Poison ivy is very difficult to kill, but 8 tons of common rock salt per acre will kill this plant and prevent growth the second year, provided smaller applications are made to the plants which survive the first application.

2. Two and $2\frac{1}{2}$ tons of salt per acre kill the ground vegetation and many weeds, but the effect does not last long enough to give good results.

3. Three to four tons of salt per acre is not sufficient to kill all deep-rooted plants, such as poison ivy, five-leaved ivy, sassafras, wild grape, and wild cherry; but these amounts do affect these and other plants and check growth sufficiently to show an appreciable difference between treated and untreated plots.

4. As a rule, 5 to 6 tons per acre is effective if conditions are favorable; that is, when applications are made on a rainy day or when rain occurs within a few days, and when all vegetation is cut.

5. Eight tons of agricultural salt will kill all vegetation except asparagus.

6. Salting is most effective about mid-season, or shortly thereafter.

7. High and rank vegetation should be cut immediately before or after applications.

8. Table salt dissolves less rapidly and is less effective than ground rock salt, commonly known as agricultural salt.

9. Deep-rooted plants are very difficult to kill, especially grape, five-leaved ivy, poison ivy, wild cherry, hackberry, sumac, and sassafras, in the order

named. Pigweed and ragweed are not much affected by the salt. Asparagus is apparently unaffected even by heavy applications.

10. It is thought that the chlorine ion, taken up in small quantities by the plants tested, stimulated growth; but when absorbed in large quantities caused injury and death.

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EXPERIMENTS WITH COMMON ROCK SALT: III. AFTER-EFFECTS OF SALT[1]

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Salt is one of the most effective herbicides and one of the most useful materials for sterilizing the soil. But those who use salt as a means for killing undesirable vegetation along drive-ways and railroads, on tennis courts, and the like, have often noticed that, while a heavy application of salt subdues the vegetation for a period of from 18 to 24 months, as soon as the excess of salt goes out of the soil, the residue apparently acts as a fertilizer; and one or two years after the treatment the vegetation on the treated places is frequently more vigorous than that on untreated areas alongside.

The after-effects of salt on alfalfa, rye grass, rye, silver beet, wheat, rape, Canada grass, and field pea have been studied by Ewart (1). He made applications of from 200 to 6400 pounds of salt per acre, duplicating each time the amounts used on the foregoing plots. In the second year after the treatment insufficient salt remained to injure the crops directly, and a decided increase occurred in most of the crops tested.

The experiments on weed eradication conducted in 1919 and reported in another paper (4) were used in 1920 to determine the after-effects of the salt. Plots treated with 3 tons of salt per acre showed no decided difference in weed growth from the check plots in October, 1920, except that pigweed seemed more abundant. Plots which received applications of 3.5 and 4 tons per acre had fewer weeds than the check plots, and the number of weeds on the plots which had received 5 tons of salt were not more than 40 to 50 per cent of those on the check plots, while some species of weeds did not reappear at all. The growth of poison ivy on these plots was decidedly less than in 1919, as could be seen by a general counting of sprouts. If applications are made heavy enough, weed growth seems to be prevented for a period longer than two growing seasons. On the other hand, when but 2 and 2.5 tons of salt per acre were applied, weed growth seemed far more abundant than that on the check plots at the end of the second growing season.

Experiments made in the spring of 1919 (2) in a cut-over swamp near the College Farm at New Brunswick, New Jersey, with a number of selected tree

[1] Paper No. 41 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

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TABLE 1

Condition of tree stumps 4 months and 18 months after treatment with common rock salt

STUMP NUMBER	VARIETY	SALT APPLIED	CONDITION AUGUST 7, 1919	CONDITION OCTOBER 9, 1919
		lbs.		
1	Birch	1	Healthy appearance	Growth of new shoots good
2	Oak	1	Healthy appearance	Growth of new shoots good
4	Maple	1	Healthy appearance	Growth of new shoots good
10	Dogwood	1	Healthy	Good new shoots
11	Dogwood	2	Healthy	Good new shoots, 3 feet
14	Chestnut	2	Injured	New shoots, very vigorous, 6 to 7 feet
17	Birch	2	Vigorous growth	Very good new shoots
19	Maple	2	Seriously injured	Alive
20	Oak	2	Healthy	Extremely vigorous new shoots, 6 feet
22	Oak	3	Bluish colored, large leaves	Healthy but few new shoots, 4 feet
24	Chestnut	3	Injured	Dead, with few poor new shoots
26	Birch	3	Slightly injured	Good new shoots
27	Birch	3	Healthy	Very vigorous new shoots, 6 feet
28	Cherry	3	Healthy	Vigorous new shoots, 5 feet
33	Oak	4	Injured	Dead
34	Cherry	4	Injured	Stem dead; good new shoots, 4 feet
36	Oak	4	Main stem healthy, side stems injured	Vigorous shoots with large leaves, 5 feet
40	Birch	4	Sickly appearance	Poor new shoots, 2 feet
43	Birch	5	Top shoots dead	Very good new shoots, 4 feet
48	Maple	5	Sickly appearance	Dead
49	Oak	5	Healthy	Very good new shoots, 4 feet
52	Birch	6	Dead	Dead
54	Sumac	6	Sickly appearance	Very poor new shoots, 1 foot
55	Oak	6	Healthy	Good new shoots with large leaves, 3 feet
59	Maple	6	Dead	Dead
60	Oak	6	Healthy with bluish leaves	Poor shoots with shiny leaves, 2 feet
62	Oak	7	Injured	Very good new shoots, large leaves, 4 feet
65	Oak	7	Healthy	Poor shoots, 2 feet
66	Birch	7	Dead	Dead
69	Maple	7	Injured	Poor new shoots, 2 to 3 feet
71	Oak	8	Injured	Dead except two extremely poor shoots, ½ to 1 foot
72	Birch	8	Dead	Dead
78	Oak	8	A number of leaves brown, dried	Extremely vigorous shoots, 7 feet
79	Maple	8	All leaves dropped	Dead
81	Oak	9	Slightly injured	Extremely vigorous shoots, 7 feet

TABLE 1—*Concluded*

STUMP NUMBER	VARIETY	SALT APPLIED	CONDITION AUGUST 7, 1919	CONDITION OCTOBER 9, 1919
		lbs.		
82	Chestnut	9	Seriously injured	Dead
84	Oak	9	Partly injured	Alive, no shoots
85	Oak	9	Injured	Dead, no shoots
89	Birch	9	Seriously injured	Dead
90	Oak	9	Partly injured	Very vigorous shoots, broad, shiny leaves, 6 feet
91	Oak	9	All veins on back of leaves yellowish	Extremely vigorous stems, 7 feet
94	Maple	10	All leaves that are left are brown and curled	Dead except two very poor shoots
95	Birch	10	Most of stems dead; small new shoots	Dead
97	Ash	10	Dead except two small new shoots	Dead except two very poor shoots
100	Oak	10	Sickly appearance	Dead
101–130	Oaks, maples, birches, etc.	None	All healthy	Fairly good shoots

stumps which were treated with common rock salt, gave an opportunity to make comparative notes in the fall of 1920 on the after-effects of the salt. Unfortunately, a fire ran through a part of the woods some time in the early spring of 1920, destroying much of the tall brush but not killing the roots. Growth soon started again. Of the one hundred treated tree stumps, a number of representative stumps were selected and their condition reported in table 1.

A study of these notes shows that when the stumps were not injured by the treatment a stimulating effect of the salt resulted. If the growth was but slightly affected by the salt applications, a vigorous growth of new shoots appeared. Not only were the injurious effects overcome, but healthy shoots of from 3 to 5 feet in height were produced. This was especially true of the hardy oak. If, however, the tree stumps had been seriously injured a very poor growth of new shoots was produced. In some cases death of the stumps resulted.

Different results were observed on the plots at Bridgeton, New Jersey (3), where oak stumps were treated with salt. These stumps were cut and burned at the place before the salt was applied. Examinations made on May 15, 1919,[2] showed that on all the plots which had received salt there was much less growth than on the check plots. On the check plots there was much undergrowth of blueberry which had been killed where the salt had been applied

[2] On account of the writer's absence, the examinations were made by Dr. E. Van Alstine, of the New Jersey Agricultural Experiment Station.

broadcast. Aside from killing the small undergrowth, salt applied broadcast showed no effect. The tree sprouts were as vigorous and as early as those on the checks. A difference could be noticed on plots 7, 8 and 9 which received 4200, 4750 and 5300 pounds of salt per acre, respectively, applied on and around the stumps. A number of stumps appeared to be dead, and all vegetation was smaller and less vigorous than that on the check plots, and was not so far advanced.

During the fall of 1920 these plots were examined again and they showed very much the same conditions as were observed at the time of the earlier examination. A counting of live stumps on the plots which had received 4750 and 5300 pounds of salt per acre showed that 60 to 70 per cent of the stumps were dead or had made such slight growth that they appeared to be still suffering from the treatment. The remainder of the stumps on these plots had a far less vigorous growth than those on the check plots.

The burning over of the stumps before treatment seemed to be of great value in this effort to kill live stumps with salt. No stimulating effect could be noticed on the plots which received the smaller amounts of salt. On the contrary, all growth appeared to be less vigorous.

CONCLUSIONS

The injurious action of heavy applications of 4 and 5 tons of salt per acre was still perceptible in the second year for weeds and brush, but was practically imperceptible where medium applications of 3 and 3.5 tons of salt per acre had been made. Where small applications of 2 and 2.5 tons had been made, a fertilizing action seemed to take place.

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THE OXIDATION OF SULFUR BY SOIL MICROÖRGANISMS: I[1]

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INTRODUCTION

It is now well established that sulfur, when added to the soil, is oxidized to sulfuric acid. This can be demonstrated by the increase both of the acidity of the soil and the amount of soluble sulfates. This knowledge has been utilized in converting insoluble into soluble phosphates so as to make them more readily available for plant growth, without recourse to the use of commercial sulfuric acid, for the manufacture of superphosphates. Extensive investigations of this problem have been carried on at the New Jersey Agricultural Experiment Station (6, 8). They have established certain important facts relating to sulfur oxidation, and the formation of soluble phosphates from ground rock phosphate. A detailed review of the earlier work on sulfur oxidation in soil is given in the above mentioned publications.

A few of the results obtained that have an important bearing on the work at hand, may be summarized as follows:

1. The oxidation of sulfur in sand and soils was found to render soluble in water and in neutral ammonium citrate appreciable quantities of the phosphorus of the pulverized phosphate.
2. The oxidation of sulfur as measured in terms of sulfates paralleled the increase of available phosphoric acid.
3. The oxidation of sulfur and the rendering available of the phosphorus in rock phosphate is influenced by a biological factor. In inoculated composts (soil, sulfur and rock phosphate), all other conditions being the same, the quantity of phosphorus rendered available in 9 weeks was double that made available in uninoculated composts in 30 weeks.
4. The microorganisms which oxidize the sulfur appear to be aerobic.
5. Calcium carbonate may bring about a decrease in available phosphorus when added to sulfur-floats-soil composts.
6. Composts are more efficient in producing available phosphates in the absence of large amounts of organic materials, such as peat, fresh horse manure, old composted manure and peptone. The more soluble organic materials will bring about the greatest decrease in efficiency.
7. Sulfur-oxidizing microorganisms may develop more rapidly in the abseuce of soluble organic matter. They appear to be similar in this respect to the nitrifying organisms.
8. When peptone was added to a mixture of soil, sulfur and floats, the sulfur was transformed largely into sulfites.

[1] Paper No. 42 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

These conclusions were based entirely upon the results obtained with crude cultures of bacteria in the composting of sulfur, floats (phosphate rock) and either soil, sand or manure. The present paper deals with an organism which oxidizes sulfur very rapidly, and which has been grown in pure culture for many generations. The methods used in the isolation of the organism (or one of the organisms) concerned in the oxidation of sulfur, are described, and an attempt is made to interpret the work of Lipman and McLean (8) and of McLean (6), in terms of the changes produced by pure culture of the sulfur-oxidizing bacteria.

THE ISOLATION OF THE SULFUR-OXIDIZING ORGANISM

A fairly comprehensive bibliography on sulfur-oxidizing organisms is found in a recent paper by Düggeli (3). It may be noted in this connection that in most of the work on the oxidation of sulfur by microorganisms, the starting point was not elementary sulfur, but hydrogen sulfide, sulfides or thiosulfates. The oxidation of sulfur was measured, in most cases, not by the production of sulfuric acid and sulfates, but either by the disappearance of sulfide in the medium, or by the appearance or disappearance of sulfur granules within or without the microbial cell. Then, we must point out the fact that most of the earlier investigations have dealt with organisms isolated from sulfur springs, salt and fresh waters and curative muds in Russia, and only a few investigations were concerned with sulfur-oxidizing organisms in the soil. Of the latter, the most important are those of Beijerinck (1) and Jacobsen (4, 5) who have described two sulfur-oxidizing organisms, *Thiobacillus denitrificans and Thiobacillus thioparus* which oxidize sulfides, thiosulfates and elementary sulfur. A comparison of these organisms with the one ioslated by the writers is published elsewhere (10).

The oxidation of sulfur in the composts (sulfur-rock-phosphate mixture) is always accompanied by an intense acid production, even in the presence of a neutralizing agent, in this case, the tri-calcium phosphate. We may cite here a table from a paper by Lipman and Joffe (7).

Change of pH value in the oxidation of sulfur in sulfur-rock-phosphate composts

	TIME OF INCUBATION													
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	8 weeks	9 weeks	10 weeks	12 weeks	14 weeks	16 weeks	18 weeks	20 weeks
pH	4.4	3.0	2.8	2.8	2.6	2.4	2.6	2.4	2.3	2.2	2.3	2.2	2.0	2.0
Available P, (per cent)	3.75	4.38	14.90	15.44	19.11	27.2	33.4	34.9	44.2	59.9	61.0	66.6	77.6	85.1

The acidity shows a rapid gain, then a slow variable change, then a rapid increase again, but much smaller than the first.

It is characteristic that the phosphate becomes soluble only after a definite period of composting which results in a rise in acidity as expressed in terms of hydrogen-ion concentration. Hence, the organism or organisms concerned in the oxidation of the sulfur would be expected, when isolated in pure culture, to produce an intense acidity in the medium.

Much preliminary work was carried out before the proper medium and methods were developed for the isolation of the organisms. Only such of the experiments will be reported here as have led to the direct isolation of the organisms concerned.

PRELIMINARY MEDIA USED

Medium A

	gm.
$(NH_4)_2SO_4$	2.00
K_2HPO_4	1.00
$MgSO_4$	0.50
KCl	0.50
$FeSO_4$	0.01
Dextrose	10.00
Sulfur	10.00
$Ca_3(PO_4)_2$	10.00
Distilled water	1000.00

Medium B

Same as A, but 1 gm. of dextrose was used in place of 10 gm.

The hydrogen-ion concentrations of these media, after sterilization, was pH = 6.0 to 6.2. All the constituents, with the exception of the tri-calcium phosphate and sulfur, were first dissolved in water; 100-cc. portions of the medium were then distributed in 250-cc. Erlenmyer flasks, the tri-calcium phosphate and sulfur were weighed out separately, and 1-gm. portions of each were added to each of the flasks. The flasks were then plugged with cotton and sterilized in flowing steam for 30 minutes on three consecutive days. The flasks and contents were always incubated, after inoculation, at 26° to 28°C.

METHODS OF ANALYSIS

At the end of a definite incubation period, the culture was filtered, and 17 cc. of the filtrate used for the following determinations:

1. The pH values were obtained from 2-cc. portions of the culture by the use of the colorimetric method, the phenolsulfonphthalein series of indicators being used, as outlined by Clark and Lubs (2).

For pH determinations of less than 1.2, the indicators mauvein and methyl-violet were used, as suggested by Sörensen (9), and checked by the electrometric method.

2. Titratible acidity was determined by titrating 5 cc. of the culture against 0.1*N* NaOH, with phenolpthalein as an indicator. The amount of the NaOH used per 1 cc. of the culture was recorded as titratible acidity (or titration).

3. Soluble sulfates were determined as follows: 5 cc. of the culture was neutralized with ammonia, acidified with 1 cc. of concentrated hydrochloric acid, diluted to 150 cc. and the sulfates precipitated, at the boiling point, with 10 cc. of 1.0*N* $BaCl_2$ diluted to 50 cc. From the weight of the $BaSO_4$ obtained the amount of soluble sulfates was calculated as SO_4 for 100 cc. of the original culture.

4. Insoluble sulfates were determined as follows: The residue from 100 cc. of culture in one flask, after filtering off the liquid, was treated with 10 cc. of concentrated hydrochloric acid and 150 cc. of distilled water, and the contents digested on a water bath for four to five hours. This brought into solution everything except the unoxidized residual sulfur. The liquid was decanted into the filtrate originally obtained (or residual part thereof); the undigested residue was then washed with distilled water until no test for sulfates could be obtained in the liquid. Occasionally, a second digestion for one or two hours with 5 cc. of hydrochloric acid was required. The filtrates were collected and made up to volume; an aliquot portion was taken and the sulfate determination was made according to the method described under paragraph 3. This gave the total sulfates present. If a part of the original filtered culture was used for the other determination, the soluble sulfates present in the 17 cc. used for those determinations were added. By subtracting the soluble sulfates from the amount of total sulfates, the insoluble sulfates were obtained.

5. The soluble phosphates were determined gravimetrically in a 5-cc. portion according to the methods of the Association of Official Agricultural Chemists. The percentage of soluble phosphates was calculated by dividing the difference between the soluble phosphates in the culture and the soluble phosphates in the control by the difference between the total phosphates and the soluble phosphates in the control.

6. The residual sulfur was found by washing into a Gooch crucible the residue from the hydrochloric acid digestion, obtained as described in paragraph 4. It was then dried in an electric oven at about 60°, until constant weight was obtained.

Procedure

Small samples were taken from composts, in which the oxidation of sulfur was well advanced, and brought into the laboratory. Several flasks of the two media were inoculated with 1-cc. suspensions made from the different composts. Different dilutions were used so as to free, if possible, the sulfur-oxidizing organisms from any contaminating organisms. The dilutions used were: 1:10, 1:1000, 1:100,000, and 1:10,000,000.

It may be seen in the table 1 that while good growth was obtained with the lower two dilutions in both media, oxidation of the sulfur, as expressed by the change in reaction, was observed only in medium B. But a slight change in reaction was observed in medium A.

Since the only difference between the two media was the dextrose content, one might assume that an excess of dextrose (1 per cent) would be injurious to the development of the sulfur-oxidizing organisms. The H_2S odor in the culture of A, with the lower dilution, would indicate reduction rather that oxidation phenomena. However, to get further light on the influence of dextrose upon the development of the organism in question, transfers were made from the cultures with the lower dilutions (1:10 and 1:1000) in A and B to fresh sterile flasks containing the same media as in the flasks from which the transfers were made.

To test further the action of this culture on medium I, a series of flasks were inoculated alike (by means of a platinum loop) and incubated.

TABLE 1

The growth of sulfur-oxidizing organisms in artificial culture media

	MEDIUM A				MEDIUM B			
	1:10	1:1000	1:100,000	1:10,000,000	1:10	1:1000	1:100,000	1:10,000,000
Growth*.....	3	4	Trace	None	4	3	2	None
Odor.....	H_2S	H_2S	None	None	Pungent	None	Faint H_2S	
pH at start....	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
pH at the end of 7 days.....	5.9	5.5	6.0	6.0	3.0	3.8		
pH at the end of 14 days.....	5.4	5.5	6.0	6.0	2.8	3.3	4.4	6.0

*2 = poor, 3 = fair, 4 = good.

The influence of dextrose in preventing the rapid oxidation of the sulfur is revealed in table 2. In the presence of dextrose, the pH of the medium became, on transfer, 5.6, 5.2 and 4.9 after 7, 14 and 21 days, respectively, for the lower dilution, and 4.9, 3.8 and 4.0 for the higher dilutions, on the corresponding dates; with only 0.1 per cent of dextrose the pH became 2.0, 1.9 and 1.9 for the lower dilutions on the same dates. This was also accompanied by a greater accumulation of soluble sulfates and phosphates. The same relationship held true on successive transfers with the only difference that it took a longer period of time to bring down the pH value to the same point.

TABLE 2

Development of sulfur-oxidizing organisms in first transfer with the same culture medium

MEDIUM	DILUTION	INCUBATION				GROWTH	SOLUBLE PHOSPHATES (AS P) IN 100 CC. IN 28 DAYS	SOLUBLE SULFATES (AS SO_4) IN 100 CC. IN 28 DAYS
		7 days	14 days	21 days	28 days			
		pH	*pH*	*pH*	*pH*		*mgm.*	*mgm.*
Control.....		5.8	5.8	5.8	5.8	0	44.5	207.0
Medium A.....	1:10	5.6	5.2	4.9		4	40.9	
	1:1000	4.9	3.8	4.0		3		
Medium B.....	1:10	2.0	1.9	1.9	1.8	4	74.2	542.7
	1:1000	1.9	1.6	1.5	1.6	4	77.2	779.5

The complete elimination of dextrose from the medium led to a more rapid oxidation of sulfur, as shown by a greater acidity and larger amounts of soluble

and insoluble sulfates accompanied by larger amounts of soluble phosphates, indicating that a dextrose-free medium was more favorable for the development of the organism. This medium consisting of the pure minerals in amounts given above under A and B, was now adopted for constant work and called medium I. The only difference between this medium and the other two preliminary media, was the complete elimination of dextrose in the former. When 100-cc. portions of this sterile medium in 250-cc. Elenmeyer flasks were inoculated from the cultures grown in the third transfer on the previous medium containing 0.1 per cent of dextrose, the results shown in table 3 were obtained.

TABLE 3

The development of the sulfur-oxidizing organisms on dextrose-free medium (Medium I)

AGE OF CULTURE	pH	SOLUBLE PHOSPHATES (AS P) IN 100 CC.	SOLUBLE SULFATES (AS SO_4) IN 100 CC.	TITRATION
days		*mgm.*	*mgm.*	*cc.*
Control	6.0	44.5	185.1	0.16
7	1.8			
14	1.2			
21	1.3	77.3	962.5	2.09

The impure cultures of the sulfur-oxidizing organisms are thus found to possess very strong oxidizing properties, 188 mgm. of the sulfur having been oxidized in 14 days, and 260 mgm. in 28 days. The conversion of the tri-calcium insoluble salt into soluble di- and mono-calcium phosphates brought about an exhaustion of the medium in basic substances and, therefore, to a slower accumulation of acids, resulting from the oxidation of the sulfur. This explains the slower oxidation of sulfur after the initial period of rapid oxidation. Sulfuric acid produced from the oxidation of sulfur reacted with the insoluble tri-calcium phosphate and converted it into soluble forms. In 7 days, we already find nearly 116 mgm. of phosphorus, or 73.6 per cent of the original material, converted into soluble forms. The reason that not all the phosphate was made water-soluble is explained by the fact that the tri-calcium phosphate is converted into di- and mono-calcium phosphate, of which only the latter is completely water-soluble, while the former is only slightly soluble in water.[2]

Thus far the work had been carried out not with the pure, but with crude cultures of sulfur-oxidizing organisms. At first molds and bacteria would develop, particularly in the presence of dextrose and in the lower dilutions.

But with the higher dilutions and with the elimination of dextrose from the medium, the molds were eliminated and only a bacterium developed which did not form any pellicle on the surface of the medium but grew throughout the medium, making it uniformly turbid. The bacterium, a minute rod-shaped organism, was accompanied by a larger one, which did not occur uniformly in the different media and repeated transfers.

[2] The physico-chemical principles involved will be taken up in a later paper.

Attempts to cultivate the organisms on various organic and inorganic solid media failed. Media containing flowers of sulfur, reprecipitated sulfur, or sodium thiosulfate as a source of energy, in addition to the other minerals, and washed agar or silica jelly as a solidifying agent, did not produce any growth. To obtain pure cultures in the liquid media, the problem was attacked in three different ways:

1. By transferring the culture repeatedly into flasks with sterile medium (no. I) having uniform composition.
2. By using high dilutions of the cultures on transfer, so as to eliminate the contaminating organisms.
3. By starting with a medium of a high acidity.

It was expected that the organism which does not oxidize sulfur would probably not be able to develop at the very high acidity, even if a few cells were introduced into a fresh portion of the medium. By the use of all these three methods of procedures, we finally succeeded in eliminating the contaminating organisms, leaving the sulfur-oxidizing bacterium in pure culture.

The purity of the culture could be demonstrated only microscopically, since the organisms refused to grow so far on any of the solid media tried. The use of very high dilutions (1:100,000) in obtaining the culture and in several transfers, as well as the high initial acidity used in a few instances (up to a pH = 2.0) tended to eliminate the contaminating organisms and leave only the bacterium that can use elementary sulfur as the only source of energy, and CO_2 from the air as the only source of carbon. The purity also was proven physiologically (negative proof) by inoculating the organism upon various media commonly employed for microbiological work, without any growth taking place.

The organism was kept in culture on medium I and transferred about every 7 to 14 days. Although it continued to live in this medium, it seems that the high acidity exerted a deleterious action upon it, for on continued transfer, it took a longer period of time for the reaction (pH value) to reach a certain point than on previous transfers, thus indicating that the vitality of the organism was gradually diminishing on continued cultivation on artificial culture media. Also, in transferring, larger amounts of inoculum were required to produce a good growth. This may probably be due to the fact that a large number of the bacteria in the inoculum were dead cells, or had lost their vitality or ability to reproduce.

COURSE OF SULFUR OXIDATION BY THE SULFUR-OXIDIZING BACTERIUM

To follow in detail the process of sulfur oxidation, acid production and conversion of tri-calcium phosphate into soluble forms, a set of 60 flasks (250-cc. Erlenmeyer) each containing 100-cc. of medium I were prepared and sterilized. All the flasks were inoculated alike from the same culture and placed in the incubator. At the end of various intervals, 3 to 6 flasks were

taken at random from the set of 60 or remaining flasks and analyzed. The results are averaged and presented in table 5.

On studying the results presented in table 5, we observe some very important facts concerning the oxidation of sulfur, production of acid and transformation

TABLE 4

The oxidation of sulfur and the transformation of insoluble calcium phosphate into soluble phosphates by impure cultures of sulfur-oxidizing organisms

AGE OF CULTURE	pH	SOLUBLE SULFATES (AS SO_4) IN 100 CC.	INSOLUBLE SULFATES IN 100 CC.	TOTAL SULFUR OXIDIZED	PROPORTION OF THE TOTAL SULFUR ADDED THAT WAS OXIDIZED	SOLUBLE PHOSPHATES (AS P) IN 100 CC.*	INSOLUBLE PHOSPHATES MADE WATER-SOLUBLE
days		*mgm.*	*mgm.*	*mgm.*	*per cent*	*mgm.*	*per cent*
Control	6.0	185.1	0.0	0.0	0.00	44.5	20.4
7	2.0	503.9	0.0			160.3	73.6
14	1.8	352.0	354.0	188.0	18.80	147.2	67.5
21	1.6						
28	1.4	403.7	398.1	260.5	26.05	149.1	68.5

* Total phosphorus in 100 cc. of the medium (as P) = 217.9 mgm.

of tri-calcium phosphate into soluble forms. The results are quite irregular, in spite of the fact that each of these represent averages of three or more flasks. But in view of the fact that a detailed study of the metabolism and life history of this organism has not been made as yet, as well as the fact that

TABLE 5

Course of reaction of the sulfur-oxidizing organisms

AGE OF CULTURE	pH	TITRATION	SULUBLE SULFATES (AS SO_4) IN 100 CC.	INSOLUBLE SULFATES (AS SO_4) IN 100 CC.	TOTAL SULFATES (AS SO_4), IN 100 CC.	PROPORTION OF THE TOTAL SULFUR ADDED THAT WAS OXIDIZED	SOLUBLE PHOSPHATES (AS P) IN 100 CC.*	INSOLUBLE PHOSPHATES MADE WATER-SOLUBLE
days		*cc.*	*mgm.*	*mgm.*	*mgm.*	*per cent*	*mgm.*	*per cent*
At start	5.4	0.16	209.78	0.00	209.78	0.00	45.57	0
1	5.4	0.15	207.77	0.00	207.77	0.00	42.61	−1.7
2	5.3	0.18	213.98	0.00	213.98	0.14	47.20	0.9
4	4.6	0.24	226.30	20.30	246.60	1.22	55.00	5.5
6	3.5	0.62						
8	2.6	0.94	468.03	159.39	627.42	13.92	103.56	33.7
10	2.7	0.85	336.61	159.75	496.36	9.55	92.97	27.5
12	2.5	0.90	241.54	307.68	549.22	11.32	186.30	81.7
15	2.4	1.00	269.69	295.45	565.14	11.85	207.28	93.9
19	2.3	1.09	288.56	278.97	567.53	11.93	194.20	86.3
23	2.4	1.09	300.22	262.97	563.19	11.78	193.45	85.9
30	1.7	1.73	486.75	351.40	838.15	20.95	193.85	86.1
38	1.8	1.60	288.64	377.52	666.16	15.21	(146.8)	(58.8)
68	1.7	1.95	376.58	343.31	719.89	17.00	193.57	85.9
120	0.8	6.80						

* Total phosphates in solution (as P) = 217.8 mgm.

we are in the dark as to the influence that the concentration of acid in the mother culture has upon the vitality of the organism, the influence of the age of the mother culture, amount of inoculum, etc., may have to do with the great variability of the individual flasks. Since investigations on these facts have not been brought as yet to any successful conclusion, we might attempt to consider the results presented in table 5 at their face value without attempting to make any sweeping conclusions.

The increase in acidity expressed in terms of both hydrogen-ion concentration and titratable acidity, is found to rise steadily with the increase in the period of incubation. The slight irregularities are due to the variability pointed out above. We find two important changes, one corresponding to the period between 4 and 8 days, when there is a rapid increase in acidity accompanied by a large accumulation of soluble and insoluble sulfates. We will note that the solution of the tri-calcium phosphate lags behind the increase in acidity and soluble sulfates: from the fourth to the eighth day there is a change in pH from 4.6 to 2.5 (2.5–2.7), and in titration from 0.24 to 0.94, while the soluble sulfates increased from 226.3 mgm. per 100 cc. to 468.03 mgm. and the insoluble sulfates from 0 to 159.39 mgm. per 100 cc. The phosphates also show an increased solubility from 5.5 per cent in 4 days, to 33.7 per cent in 8 days. But the largest amount of soluble phosphates is found in 12 days. The increase between 8 and 12 days is from 33.7 to 81.7 per cent of the total insoluble phosphates in 100 cc. of medium. This is explained by the fact that the oxidation of sulfur and production of sulfuric acid and soluble sulfates precedes the solution of the insoluble phosphates.

The transformation of the insoluble phosphates into soluble forms is a result of the production of sulfuric acid; this is accompanied by a corresponding decrease in soluble sulfates, and a rise in the amount of insoluble sulfates. The hydrogen-ion concentration and titratible acidity remain more or less stationary during the rapid transformation of the insoluble phosphates, since the acid produced is used up; but, as soon as all insoluble phosphate has been made soluble (in about 23 days), the acidity begins to increase on account of the accumulation of free acids.

The most striking thing in the experiment is the solution of the insoluble phosphate to the extent of 81.7 per cent in 12 days and 93.9 per cent in 15 days. Since these amounts were never increased, even in 68 days, we must conclude that all the insoluble phosphate became soluble in the pure culture in the period of 12 to 15 days, and the salts in the culture have come to a state of equilibrium. The fact that only 81.7 to 93.9 per cent of the phosphate is found in water solution would lead us to assume that some of the phosphate is either present in the di-calcium form and was carried down together with the crystalline calcium sulfate, or that the drying out of the culture in the prolonged experiment involved certain errors in the determinations; also some of the phosphate was assimilated by the organisms. This leads us to conclude that, in the presence of an excess of sulfur, the pure culture of the sulfur-

oxidizing organisms will convert all the insoluble phosphate, or at least 86 to 94 per cent of it, into water-soluble phosphate in a period of about 15 days, under proper experimental conditions.

After the fifteenth day, the phosphate concentration in the solution has reached an equilibrium (with due consideration to the variabilty of the individual flasks). The further oxidation of the excess of sulfur in the medium leads to the accumulation of free sulfuric acid; this acts upon the soluble calcium phosphates, transforming them into phosphoric acid and both soluble and insoluble sulfates. The physico-chemical relations of the phosphates and

TABLE 6

*Vitality of the sulfur-oxidizing organisms on continued transfer**

GENERATION	AGE OF CULTURE	pH	TITRATION
	days		*cc.*
Control		6.2	0.16
Third	7	1.8	
Third	14	1.2	
Fourth	21	1.6	
Fourth	28	1.4	
Fourth	81	0.6	3.65
Fourth	83	0.6	4.00
Fifth	7	3.6	
Fifth	14	2.0	
Fifth	68	1.9	1.70
Fifth	75	0.6	4.20
Sixth	7	4.0	
Sixth	21	2.8	
Sixth	61	1.8	2.00
Seventh	33	2.6	1.05
Seventh	46	2.6	1.10
Seventh	61	1.8	2.25
Eighth	33	2.2	1.25
Ninth	33	3.8	0.70

* Same medium (dextrose-free) was used throughout.

sulfates in solution will be taken up in detail in a later paper. For the present we will limit ourselves to general considerations. The pH of the medium gradually decreases and the titration increases, accompanied by an increase in total sulfates. In 120 days the culture is found to be equivalent to 0.68 *N* acid. Of course the acid is a mixture of sulfuric and phosphoric, and the titration indicates not only the free acid, but also the acid salts. The hydrogen-ion concentration of the solution gives a truer indication of its acidity. The pH of the solution is found in 120 days to be 0.8 (in other cases, the reaction has gone down to 0.58 pH and less), which is equivalent to more than 0.1 *N* acid all dissociated.

The organism was grown on medium I for a period of 8 months. But, on consecutive transfer, it was observed that it takes a longer period of time to bring the reaction down to the same point, as shown in table 6.

The data in the above table indicate a definite deterioration of the sulfur-oxidizing capacity of the organisms, on continued cultivation in artificial, liquid culture media. While in the third generation it took the organism 14 days to bring the acidity of the medium to a pH of 1.2, in the fifth generation it took over 68 days to produce the same acidity, and in the sixth and seventh even after 61 days, the same concentration of acid was not yet obtained. The titration of the culture, which expresses in terms of 0.1 *N* NaOH, how much alkali was required to neutralize 1 cc. of the culture with phenolphthalein as an indicator, runs parallel to the hydrogen-ion concentration of the culture.

To throw further light on the question of the deterioration of the culture when grown for successive generations on artificial culture media, several experiments were carried out, the results of which are reported below.

INFLUENCE OF INITIAL REACTION UPON THE GROWTH OF THE ORGANISMS

For the study of the influence of the initial reaction of the medium upon the growth of the organism and its ability to oxidize sulfur, various amounts of phosphoric acid and phosphates were added to medium I.

The series was arranged as follows:

	*p*H.
90 cc. of medium + 9 cc. 1.0*N* H_3PO_4 + 1 cc. 1.0*M* KH_2PO_4	2.0
90 cc. of medium + 8 cc. 1.0*N* H_3PO_4 + 2 cc. 1.0*M* KH_2PO_4	2.2
90 cc. of medium + 5 cc. 1.0*N* H_3PO_4 + 5 cc. 1.0*M* KH_2PO_4	2.5
90 cc. of medium + 3 cc. 1.0*N* H_3PO_4 + 7 cc. 1.0*M* KH_2PO_4	2.8
90 cc. of medium + 1 cc. 1.0*N* H_3PO_4 + 9 cc. 1.0*M* KH_2PO_4	3.4
90 cc. of medium + 10 cc. 1.0*M* KH_2PO_4	4.2
90 cc. of medium + 9 cc. 1.0*M* KH_2PO_4 + 1 cc. 1.0*M* K_2HPO_4	5.6
90 cc. of medium + 7 cc. 1.0*M* KH_2PO_4 + 3 cc. 1.0*M* K_2HPO_4	6.5

The media thus buffered, free from any insoluble phosphates or other neutralizing agents, were sterilized, inoculated alike in duplicate from the same mother culture, and incubated. At the end of 15 days the cultures were examined as to growth indicated by the turbidity formed, change in pH value, formation of soluble sulfates and the disappearance of elementary sulfur.

The reaction of the medium, properly buffered and ranging from pH = 2.8 to 2.0 gave the best growth, accompanied by a greater oxidation of sulfur as indicated by the range in pH and production of soluble sulfates. A reaction corresponding to the pH value of 5.6 and more is not favorable for the development of the organism, while a reaction corresponding to a pH between these limits will allow a development of the organisms, but will probably require a greater period of time for its action.

These results have a direct practical bearing. The organism has its optimum within the limits of reaction, roughly defined between pH = 3.0 to 2.0, this, of course, depending on the concentration of buffer material in the medium. When the organism is inoculated upon the medium having an optimum reaction, it begins to develop at once and oxidize sulfur, resulting in a rapid accumulation of acid. But when the medium is at pH = 3.0 to 5.6, the organism is still able to develop, but very slowly. Particularly is the growth checked by the presence of an excess of insoluble alkaline calcium salts, because the acid produced will at first be used up in dissolving these salts, and only after the neutralizing agent has gone into solution, will the reaction be brought to a point optimum for the activities of the organism. This point is very important and we will come back to it again.

TABLE 7

Influence of initial reaction of the culture on the oxidation of sulfur

INITIAL pH	FINAL pH	SOLUBLE SULFATES AS SO_4 IN 100 CC.	TURBIDITY (GROWTH)*
		mgm.	
2.0	1.2	614.92	5
2.2	1.9	—	5
2.5	1.85	555.17	4
2.8	1.9	569.20	4
3.4	2.2	418.44	2
4.2†	2.0	537.46	3
	2.6	370.04	1
5.6	5.6	265.26	T
6.5	6.5		0
Control	6.2	210.00	0

* 0 = none, T = trace, 1 = scant, 2 = poor, 3 = fair, 4 = good, 5 = very good.
† Duplicates not checking.

Since our medium no. I contains 1 gm. of tri-calcium phosphate which will tend to keep the medium less acid, until it has all been converted into mono and di-calcium salts, the question as to how this presence of calcium affects the growth and the vitality of the organism was presented. As pointed out above, the vitality of the culture continually deteriorated on constant transfer. It was then decided to isolate the organism again from the soil by using medium I, but it developed only slowly and was badly contaminated with fungi, particularly in the presence of dextrose. In view of the fact that no solid medium has been developed as yet for the isolation of the organism, the continuous growth on the liquid medium for the purpose of obtaining pure cultures was a lengthy and tedious procedure. A detailed study was then undertaken of the influence of acids, particularly sulfuric and phosphoric; bases, particularly calcium; and carbohydrates upon the growth of the sulfur-

oxidizing organism, both at the point of isolation from the composts and in continuous transfer. This resulted in the development of new culture media, which can be used for the direct isolation of the organism from the soil and for demonstrating its presence in the soil and other substrata. This will form the subject of one of the ensuing papers from this laboratory.

The organism survives in very concentrated acid solutions, equivalent to as much as 0.8 *N* acid, which is a mixture of sulfuric and phosphoric acids, and mono-calcium phosphate. The hydrogen-ion concentration of the medium may go down to as low as pH = 0.58, without killing the organism and without injuring its ability of reproduction.

The acid, however, acts destructively upon the vitality of the organism and it was found that on transferring more often (about every 4 to 7 days), when the reaction has not gone down below pH = 1.4 to 1.6, the vitality and activity will be much greater.

On the other hand, the alkalies act detrimentally upon the activities of the organism, so that the growth will be very slow in the presence of an excess of $CaCO_3$, at a reaction equivalent to pH = 6.0 and above. Growth is rather slow until enough acid has been accumulated for the complete neutralization of tri-calcium phosphate, then it proceeds at a more rapid pace. When $CaCO_3$ is used as a neutralizing agent, growth may not take place at all, because the presence of the carbonate will tend to neutralize any acid formed and keep the medium at a slightly alkaline reaction, which will prevent any development of the organism.

DESCRIPTION OF THE SULFUR-OXIDIZING ORGANISM

A detailed morphological and physiological study of the organism will be given elsewhere (10). The organism is somewhat related to the two Thiobacilli described by Beijerinck and Jacobsen and was therefore classified in the genus *Thiobacillus*. *Thiobacillus thiooxidans* is a short rod, with round edges, almost spherical, with a tendency to occur in pairs. It is less than 1 μ long and about 0.5 μ in diameter. It is autotrophic, deriving its carbon from the CO_2 of the atmosphere and its energy from the oxidation of sulfur, also thiosulfate. The presence of organic materials is not injurious to its growth; as a matter of fact, certain substances, such as dextrose, glycerin and alcohol, present in small quantities (0.1 per cent), may prove beneficial to its initial growth at least. However, this subject has not been fully investigated as yet. As nitrogen sources, it can use ammonium salts and nitrates, but since the first tend to leave the medium more acid than the second, the first are preferred. The mineral requirements are limited, so that only potassium phosphate will supply this need; however, since no care was taken as yet to eliminate the iron, magnesium and traces of other minerals from the distilled water and glass containers, it is not safe to state that these are not required.

THE IMPORTANCE OF THE ORGANISMS IN THE SOIL ECONOMY

The general relations of sulfur-oxidizing organisms in cultivated soils are not well understood. The facts already at hand would seem to indicate that these organisms are present in practically all cultivated soils. This assumption is justified by the fact that more sulfur is oxidized in unsterilized than it is in corresponding sterilized soils. Future investigations must determine how many species of sulfur-oxidizing bacteria there are and how these differ in their metabolic processes.

Many important applications are already indicated. For one thing, they can be made and have already been made an important aid in modifying soil reaction. By adjusting the quantities of sulfur employed practically any reaction within given limits may be established. Soil acidity great enough to prevent the development of the potato scab fungus can be readily created. Yet, the acidity thus developed need not be intense enough to interfere with the production of large crops of clean potatoes. By the use of still-larger quantities of sulfur the soil may be made so acid as to prevent the development of soil-infesting insects, including such troublesome insects as wireworms and white grubs. The degree of soil acidity may be raised to a point where undesirable weeds or other plants would be eliminated. It would be possible later to correct this acidity by the use of lime or of other basic materials.

There is promise that, through the use of sulfur and suitable cultures of sulfur-oxidizing bacteria, black alkali soils may be reclaimed. In this case the injurious carbonate and bicarbonate of sodium would be gradually changed into the less injurious sodium sulfate. Preliminary experiments already carried out in our laboratories show that this is quite feasible.

The sulfuric acid produced when sulfur is oxidized in the soil may serve as an effective solvent. The supply of available phosphates and of potassium and calcium or magnesian compounds may thus be readily increased. In certain soil regions the use of sulfur and of sulfur-oxidizing bacteria for this purpose may be of considerable moment.

There are extensive areas of soil that respond readily to applications of sulfates or of sulfur. The investigations at the Oregon Agricultural Experiment Station show that elementary sulfur may be used to great advantage in increasing the yields of alfalfa and of clover. Crop increases through the use of sulfur also have been obtained in other localities, although the results have not been so consistent. There is considerable evidence at hand to the effect that inoculated sulfur may be used to very considerable advantage in the growing of garden crops, even where atmospheric precipitation may supply considerable quantities of sulfur.

Composting experiments have shown that soluble phosphates may be readily produced when mixtures of mineral phosphates, of sulfur and of sulfur-oxidizing bacteria are kept under suitable conditions as to moisture, tempera-

ture and aeration. In the same way, soluble potash compounds have been produced from greensand marls containing the mineral glauconite. A number of these points are under investigation at the New Jersey Agricultural Experiment Station and the data as accumulated will be reported on in future papers.

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PRACTICAL SIGNIFICANCE OF THE ORGANIC CARBON NITROGEN RATIO IN SOILS

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In connection with certain investigations on the quantitative relationships of soil organic matter it appeared worth while to consider the significance of the organic carbon-nitrogen ratio in its relation to soil productivity. The results for carbon were obtained by the rapid dry combustion method as modified by Read (7) for the simultaneous determination of soil organic matter and organic carbon. The carbon determinations have already been presented in the preceding paper on the conventional carbon factor. The nitrogen determinations were made by the official Kjeldahl method.

Some recent studies have been reported on the carbon-nitrogen ratio as it occurs in various soils, and several investigators have suggested that certain given ratios represent certain degrees of fertility.

LITERATURE CONSULTED

Pagnoul (6) found no fixed relation between carbon and nitrogen, but the carbon, nitrogen and humus content all appeared to vary in the same direction, although irregularly.

Dyer (3) studied the carbon-nitrogen ratio of 21 Rothamstead wheat soils at 10 successive depths of 9 inches each. For the first, second, third, fourth, and fifth depths the corresponding carbon-nitrogen ratios for all plats varied as follows: 9 to 10; 7.6 to 9.7; 6.7 to 8.2; 5.6 to 7.8; 5.0 to 7.1. At the fifth and sixth depths the ratio ceased to become narrower and was little influenced by past surface accumulations.

Kaserer (5) showed that for every soil there was a certain state of equilibrium between the nitrogen and the carbon contained in the humus, which was influenced by the chemical composition and reaction of the soil and the conditions of moisture and temperature.

Stewart (8) stated that in general the carbon-nitrogen ratio of the soil tended to become narrower with the aging of the organic material, but that it never became narrower or even equal to the ratio of the proteins commonly present in humus-forming materials. He found the carbon-nitrogen ratios of the ordinary brown silt loam soils of Illinois to be 12.1, 11.5 and 8.9 in the surface, subsurface and subsoil, respectively, and in the black clay loam soils the corresponding ratios were 11.7, 11.9, and 9.

Alway and Vail (1) studied the relative amounts of nitrogen, carbon and humus in some Nebraska soils and found that the carbon-nitrogen ratio decreased through the first 3 feet in the upland prairie soils, but remained constant in the lowland fields until the black soil had been passed through. In the surface 6 or 12 inches of the prairie soils the carbon-nitrogen ratio varied from 10.2 to 12.7. The ratio of 12-inch depths in the cultivated fields was considerably lower than in the adjacent prairies. They concluded that the ratios for the surface soils were sufficiently constant to estimate the carbon content from a nitrogen determination, thereby making a carbon determination unnecessary for practical purposes, and that the percentage of humus in a soil could be estimated from its nitrogen content if similar soils from that part of the state had been analysed.

Felber (4) studied the equilibrium between the nitrogen and carbon in 13 soils, all of different geological formation and composition. His findings corroborated those of Kaserer. In the surface of arable soils the ratio varied from 8.3 to 10. The ratio was 10 in soils very rich in humus and varied from 6.6 to 7.7 in soils poor in humus. In the subsoils the proportions varied between 11 and 14 and the amounts of carbon and nitrogen decreased with the depth. His results indicated that the carbon-nitrogen ratio was sufficiently constant for different soils to encourage the elaboration of a method to determine approximately the amount of humus in a soil from the percentage of nitrogen found in that soil. Such a method implied the use of the conventional carbon factor.

Brown and Allison (2, p. 49) stated:

> The determination of the carbon-nitrogen ratio in soils is now coming to be considered of much importance in fertility studies. Not only does it show the organic matter content of soils more accurately than the more or less arbitrary humus determinations concerning which considerable difference of opinion exists, but it also throws some light upon the rate at which decomposition processes are occurring in the soil.
>
> Experience has shown that (in the case of humid soils) if the ratio narrowed beyond a point of about 1 to 10 crop yields may be reduced, evidently because of an insufficient production of available nitrogen, phosphorus and potassium. On the other hand, if the ratio was 1 to 12 or above, bacterial activities apparently occur to a satisfactory extent and sufficient amounts of soluble plant-food are produced for good crop growth.

Waynick and Sharp (9) presented data showing the amount of variation found in the total carbon and the total nitrogen in the silty clay loam soil at Davis and in the blow sand at Oakley, California. A plat of about 1.3 acres was selected at each place, the choice being made on apparent uniformity, and 100 soil samples were taken from each plot. In the Davis soils the nitrogen varied from 0.977 to 0.124 per cent and the carbon ranged from 0.896 to 1.383, while in the Oakley soil the percentage range for nitrogen was from 0.021 to 0.063 and for carbon from 0.179 to 0.947. These variations indicate the unreliability of results secured from one or possibly several determinations. The carbon-nitrogen ratios calculated from the analytical

TABLE 1

Relation of carbon-nitrogen ratio to yields of corn and wheat on 37 surface soils

REGISTER NUMBER	SOIL AND LOCATION	DEPTH SAMPLE	ORGANIC MATTER	ORGANIC CARBON	ORGANIC NITROGEN	C:N RATIO	AVERAGE ANNUAL YIELD PER ACRE	
							Corn	Wheat
		inches	*per cent*	*per cent*	*per cent*		*bu.*	*bu.*
2654	Lamoure silty clay loam (Iowa)	0–20	6.18	54.78	0.323	10.48	44	20
2656	Webster silty clay loam (Iowa)	0–15	3.62	50.62	0.203	9.03	40	20
2658	Wabash silt loam (Iowa)	0–20	6.18	55.44	0.362	9.46	42	
2660	Carrington loam (Iowa)	0– 8	4.20	54.26	0.284	8.03	33	17
2662	Fargo silty clay loam (Iowa)	0–18	6.82	53.53	0.359	10.17	31	17
2669	Shelby loam (Mo.)	0–10	1.71	50.67	0.130	6.66	35	
2672	Decatur silt loam (Mo.)	0–10	1.68	47.07	0.129	6.13	31	
2675	Grundy silt loam (Mo.)	0–12	2.70	52.93	0.207	6.90	40	
2678	Marshall silt loam (Mo.)	0–12	2.37	50.07	0.162	7.32	45	
2682	Summit silt loam (Kan.)	0– 7	4.07	53.54	0.261	8.35	27	16
2684	Laurel very fine sandy loam (Kan.)	0– 7	2.73	54.41	0.165	9.00	30	18
2686	Marshall silt loam (Kan.)	0– 7	2.68	53.42	0.185	7.74	24	17
2688	Wabash silty clay loam (Kan.)	0– 7	4.22	53.54	0.218	10.32	35	20
2690	Oswego silt loam (Kan.)	0– 7	5.59	53.32	0.282	10.57	23	16
2712	Fargo clay loam (Minn.)	0– 8	6.12	55.09	0.401	8.41	31	21
2714	Gloucester loam (Minn.)	0– 8	1.72	50.66	0.113	7.71	50	
2716	Carrington silt loam (Minn.)	0– 8	4.22	49.92	0.248	8.49	48	21
2718	Hempstead silt loam (Minn.)	0– 8	3.76	54.43	0.211	9.69	50	25
2720	Colby silt loam (Wis.)	0– 7	1.91	48.77	0.119	7.83	40	
2722	Clyde sandy loam (Wis.)	0– 7	3.70	54.54	0.228	8.85	35	
2724	Clyde loam (Wis.)	0– 7	5.26	54.64	0.361	7.96	44	
2726	Clyde silt loam (Wis.)	0– 7	4.56	52.67	0.278	8.64	53	
2728	Superior silt loam (Wis.)	0– 7	2.00	44.61	0.141	6.32	44	
2730	Waukesha silt loam (Wis.)	0– 7	1.23	44.38	0.121	4.51	46	
2732	Knox silt loam (Wis.)	0– 7	2.18	45.21	0.156	6.32	42	
2734	Westmoreland silty clay (W. Va.)	0– 7	5.40	50.49	0.308	8.85	50	
2738	Upshur clay (W. Va.)	0– 7	2.73	30.20	0.129	6.16	30	
2740	Moshannon silt loam (W. Va.)	0– 7	2.44	33.01	0.153	5.26	40	
2742	Huntington loam (W. Va.)	0– 7	5.34	36.89	0.282	6.98	45	
2744	DeKalb silt loam (W. Va.)	0– 7	2.47	37.56	0.146	6.35	25	
2746	Tyler silt loam (W. Va.)	0– 7	2.44	40.34	0.156	6.30	40	
2748	Wheeling silt loam (W. Va.)	0– 6	3.50	34.51	0.191	6.32	40	
2760	Barnes loam (N. Dak.)	0– 7	6.18	55.87	0.368	9.38	35	
2764	Fargo clay (N. Dak.)	0– 7	8.05	53.51	0.401	10.74	45	
2766	Bearden silt loam (N. Dak.)	0– 7	5.46	55.08	0.356	8.45	40	
2791	Diablo clay (Cal.)	0–12	3.30	56.27	0.183	10.15		18
2792	Diablo clay adoba (Cal.)	0–24	1.38	49.02	0.083	8.15		10

data reported for these extremes show a variation of 10.9 to 12.5 in the Davis soil and 8.1 to 20.4 in the Oakley soil. Such variation as these occurring on small areas of soil selected for their apparent uniformity would seem to discredit to a considerable extent any significance that might be given to the correlation of the carbon-nitrogen ratio with soil fertility, especially if only a relatively few samples are considered.

EXPERIMENTAL

The data presented in table 1 show the carbon-nitrogen ratio for 37 different soils, the average annual production of corn on all of these soils except the two from California, and the yield of both corn and wheat on twelve of the soils. The values for the carbon-nitrogen ratios range from 10.74 (Fargo clay) to 4.51 (Waukesha silt loam). In general the lower ratios are associated with the lower percentages of organic matter, but no correlation is shown between crop yields and the ratio of carbon to nitrogen. In fact the lowest yield of corn, 23 bushels per acre, is on soil 2690, Oswego silt loam, which has a ratio of 10.57, and the Waukesha silt loam, no. 2730, with the lowest ratio in the table, 4.51, produces 46 bushels of corn per acre. Although these are extreme variations it is very evident from an inspection of the table that a given ratio does not indicate a certain degree of productivity.

The data for the crop yields given above represent as accurate information as could be obtained from the soils divisions of the stations which furnished samples. None of the yields reported have been influenced by the use of commercial fertilizers, and practically all the samples of the different soils studied were taken in the regular soil survey work of the different stations and should be representative of the various soil types.

SUMMARY

Sixteen of the 37 soils studied contain less than 3 per cent of organic matter, and the carbon-nitrogen ratio for these soils ranges from 4.51 to 9.00. The yield in bushels of corn per acre varies from 24 to 50 on soils whose ratios are 7.74 and 7.71 respectively.

The remaining 21 soils, having above 3 per cent of organic matter, show a variation of from 6.32 to 10.74 in the ratio of carbon to nitrogen, and the yield of corn given for each of these extremes is 40 and 45 bushels, respectively. The ratio for the lowest yield of corn on the 21 soils, 23 bushels per acre, is 10.57, while that for the highest yielding soil, 53 bushels per acre, is 8.64.

A consideration of the data presented in this paper leads to the conclusion that soil productivity cannot be correlated with the organic carbon-nitrogen ratio.

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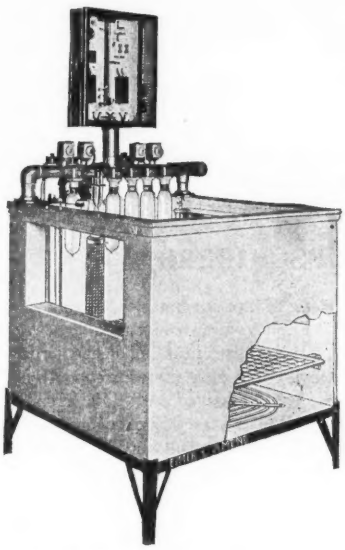
RESEARCH APPARATUS



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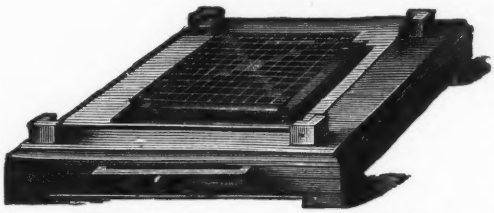

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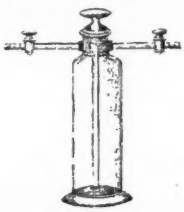

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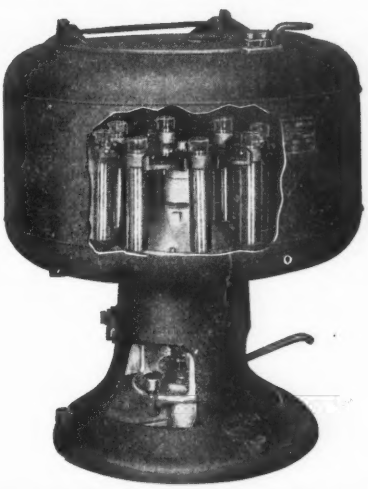

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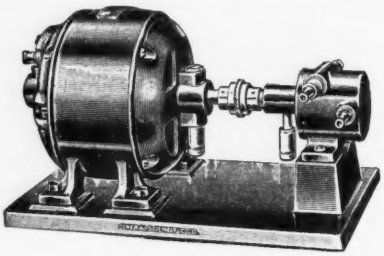

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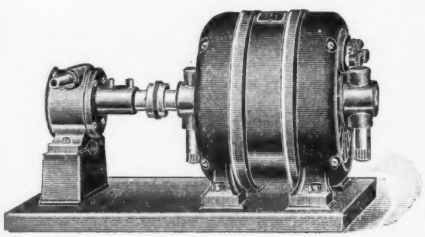

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